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STRUCTURAL STEEL; ITS PAST AND FUTURE

By G. H. Danforth*

As retiring President it has come to me, after some sixteen years in the Society, to make a farewell or, as a schoolman would say, a valedictory talk or address. In casting about for a subject, a Pittsburgh friend has settled it for me (without knowing what he was doing) by remarking to me one day that he had known me for many years as a "dyed in the wool" structural steel man and that he did not think that I ever would know anything else, and so it is that I am going to try to give you to-night some of the results of the time I have spent in the structural engineering game, for game it is, with its constant changes and variety of conditions and surroundings.

Steel construction, as it exists to-day, is the heir of that period prior to the Civil War, which saw the rise and development of the structural uses of wrought-iron for bridges and also, to a much more limited extent, for certain forms of building work. In England, both wrought- and cast-iron were used in construction much earlier than this, but in this country the abundant supplies of timber and the imperative need of building cheaply, delayed our use of metal to a later date. It was during this period that the theoretical work was done whereby we were taught the analysis of structures and the stresses that come from various types and conditions of loading, material to resist these stresses being proportioned in different ways to suit the ideas or whims of the designer. You have only to look over some of the early handbooks and treatises to see how our predecessors labored to find the best and most economical way, according to their lights, to solve their problems and make their structures safe. The Patent Office was full of the efforts of these men for at that time the idea was rampant that the patent was the thing to protect their ideas. Few of the structures of this period remain to tell the tale, having been superseded in the course of time. It

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is to this time that the Bollman and the Whipple truss belong; also the Post truss, now all practically extinct. The Pratt truss is still with us but the rest have gone. Once in a while there will appear a man with a patent on some structural design that he thinks is new and valuable, but nine times out of ten it will be found on analysis that the new patent is but one of these old ideas that has been so dressed up by the skillful patent attorney as to get by the Patent Office Examiner.

The great expansion of the railroads after the Civil War was the cause of the growth of many shops for metal construction work. Some of these shops had been originally built for the making of "combination" bridges, as they were called, having wood for top chord and posts and iron rods for tension members, the junction of the wood and iron members being usually made by means of a casting. It was but natural that these shops should develop and multiply as wrought-iron became cheaper and as the loadings became heavier. The directing minds of these shops became, eventually, the designers and fabricators of the all-metal bridge, as well as the occasional metal train-shed. At this time there was little in the way of metal buildings of any other type. The first extensive use of metal skeletons in the ordinary commercial building was made when part of the Western Union building in Chicago was constructed. This was followed in 1883 by the Home Insurance building, also in Chicago, where the first Bessemer steel beams were used in connection with cast-iron columns to form a complete frame. It is well to stop a moment and think how recently steel construction has developed, when you are trying to form an idea as to what its use may be in the future.

In considering this future, it should be borne in mind, that it is only within the past few years, that there has been any real rival to steel as a structural element in structures of any size. Wood has been displaced on account of the lack of strength and the high cost. For certain types of factory construction, known as mill construction, it is still favorably regarded but the high cost and the tendency to dry-rot are crowding it out even there, and relegating its use to ordinary house construction where loadings are light and poor grades can be used. Even here, its com-

bustibility is against it. The growing idea that construction shall be incombustible, if not fire-proof, is practically certain to cause its abandonment, except for finish or for temporary structures where ease of making connections and reuse of the material after the structure is abandoned make its use advisable.

Concrete has been used of late years to a considerable extent, and has had many enthusiastic advocates. In fact, its standing to-day has been more than impaired by this very enthusiasm, causing it to be used in places where it really had no business even to be considered. Compared to structural steel it is heavy and cumbersome and if it is to displace structural steel there will have to be ways found to insure its standing the weather, at least in this climate. The tendency of concrete to spall under heat is also against it. To spall, when used as protection against fire, is bad enough but when the spalling is from the very member on which you are depending for the strength of your structure, it is fatal. There is also the very serious objection to be urged, that it is subject to all the incidental defects involved in field work with no means of knowing what you have until it is in the structure. You cannot test it beforehand to determine what you are going to get as a finished result.

Terra-cotta has been brought forward by some and quite a number of good sized arches and domes have been built, but, so far, they seem to have defied analysis and are constructed on empirical rules, and to use this material for anything aside from the few places where it serves a special purpose is hardly possible.

So far, nothing has been developed that would indicate that the use of steel for structural purposes was on the wane, or that we are likely to see it displaced in the immediate future. Comparatively speaking, it is light in weight for the strength it possesses; there is no uncertainty as to determining its quality before it is incorporated into the structure or as to how it is connected after you get it there. It is not fire-proof but it is incombustible, and, if the use is such that protection from fire is necessary such protection can be readily applied. As made at the present day, it has to be admitted that it will rust when subjected to certain exposures, and as a protection against this we have been relying

on various paints and coatings. As the only protection against corrosion of a structure, costing many thousands of dollars, it is not logical to have a microscopically thin film of oxidized vegetable oil or something that is equally tender and fragile. Some day, no doubt, we will produce a non-corroding steel, that will be commercially available for construction purposes, and then the use of paint will be relegated to its proper place—that of finish and color only, in cases where we do not think the natural appearance preferable.

With the rise of structural steel there developed a mania for diverse specifications both for quality of the material and for workmanship on the completed structure. Every railroad and nearly every engineer developed one, and from their respective viewpoints the only right and proper one. This led to endless confusion, and an impossible situation, from a production standpoint, was created. We still have plenty of specifications of various tendencies, but, thanks to the labors of some of our engineering and other technical societies, they are getting to be more reasonable and for similar types of structures they are also getting to be more uniform. There is still room for further progress in this direction and it is to be hoped that the time is not far distant when the specifications for quality will be reduced to one for each of not more than, say, three or four types of structures. It is for work of this character that many of the societies are to be most highly praised. Workmanship specifications have to a large extent grown more rigid as the years have gone by. Punched holes, originally universal, have been barred under certain conditions and reamed holes or holes drilled from the solid have been called for in high-class work. These constitute a serious item to be considered. There seems to be a tendency however of late, at least in some quarters, to let up in this regard, as if it were considered that the results obtained were not worth the extra expense. The same can also be considered true of the epidemic of sand-blasting and, later, of pickling to remove mill-scale, that for a time ran rampant in certain places. Possibly the absence of easy money among our railroads and their need of getting value received may have had something to do with this change.

Assumed loadings in railroad bridgework have been getting steadily heavier and heavier, and many steel bridges have had to be scrapped on this account. For this reason, many roads that can afford the cost have replaced their shorter span bridges with masonry structures in which the design is made with a much larger factor of safety and which are not so likely to be overloaded by an increase in the weights passing over them. It would be entirely possible to design a metal structure with a similar factor of safety and get a longer lived structure. In building work, the tendency now seems to be toward lighter assumed loads than have prevailed. Many city codes have been revised in a downward direction, and recently there has developed a desire to increase the allowable working stresses from the 16,000 pounds per square inch, that has prevailed since the introduction of steel in the place of wrought-iron, to 18,000 or even 20,000 pounds per square inch. If this is taken in conjunction with the tendency to use a lighter assumed loading, it would appear to me that we are getting to the point where the resulting structure will lack both the rigidity and the strength in service that we have been accustomed to expect.

With regard to the future of the steel structure, there is nothing I can see that seriously threatens it—nothing that is likely to take its place. Improvements? Yes, in addition to a non-rusting material which has been referred to previously, there will probably be improvements in fabricating. Riveting is an expensive way of fabricating steel, but at the present time it is the only method we have, and the most promising substitute in sight is welding. So far it is available only for thin sections, although skin welds have been used on tanks and on a few experimental structural jobs. This will not do, however, for a job of any size. Spot welding has been used for thin matterial with a fair average of reliability. This reliability, I am told by people doing commercial work, is as high as 95 per cent. of perfect welds. As this was on material about 1/16 inch thick, and as the percentage falls rapidly with increasing thickness, you can see how far we will have to go before we can hope to do reliable commercial work with our ordinary structural material. It may be that some genius will develop a continuous weld—something between the spot weld

and the skin weld—that will solve the problem. The rolling, or otherwise making, of new sections, may reduce the amount of shop fabrication but it can not get away from the field work of putting the structure together.

To summarize this matter, I believe that the use of structural steel is to continue, and that there is nothing that is going to take its place in the future so far as can be seen at the present time. Our practice may change and our materials may improve, but it will still be steel. Designs, already simple, will be still more simple and fewer sections will be used. The habit of letting work on competitive designs, once so prevalent, will be further eliminated; and, in this, the consulting engineer will come into his own. Competition among fabricators will become a matter of quality and service and then the shop that has striven for a reputation in these directions will get its reward. The past year, which has been one of the most ruthlessly competitive years commercially, has shown that even under these conditions a buyer will not always be governed by price but will award work to a shop at a higher price if he has confidence that he is going to get value received in service.

This will not require us to live in Utopia, but will only be the applying of principles that exist in other branches of commercial life, to a field where they are sorely needed.

THE NATURE OF BRASS

By A. E. White*

To speak on brass in a steel town is unusual. For one who had his early training in iron and steel and who still attempts to maintain his major interest in iron and steel to speak on such a subject is perhaps more unusual. There may be those who wonder how one can turn easily from one of these fields to another. The answer is simple for the underlying principles in the metallurgy of brass and in the metallurgy of iron and steel are not as distinct and separate as we have, at times, been led to believe.

To be sure, there has been an attempt on the part of some of those engaged in the brass industry to maintain strict secrecy relative to the process, believing thereby they were better able to hold their positions and assure for themselves a satisfactory livelihood. One leading exponent of this class living in the Naugatuck Valley hoodwinked his employers into believing that he possessed a rare flux which made the procurement of poor brass an impossibility. This flux consisted of salt mixed with a sufficient quantity of horse dung to conceal the salt present. We all know there was nothing of value in the dung. But salt, even in those times, was known for its virtues. Yet this person was to all intents and purposes set upon a pedestal by the company for whom he worked because of the assumed secret virtues of his flux. Those days have vanished. It is safe to say that no employer of molders or casters in the brass business to-day is deceived by such hypocrisies; yet, unfortunately, the people who use brass know too little about it and must depend to too great an extent upon the recommendations of the producers. Luckily there is a strong desire on the part of most producers, if not all, to serve the interests of their customers to the best advantage. It is seldom, in consequence, that incorrect information is given if a sufficiently

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earnest attempt is made to arrive at the facts. Yet, in this business as in many others, producers are loath to advance information. It is for the purpose of throwing some light on the properties of brasses and the extent to which these properties are varied by cold working and by different degrees of annealing that this paper is presented.

No one is quite sure when metal was first used by man. We realize that the discovery of metal was one of the great turning points in man's civilization, for it involved his change from a mere being with no tools, other than his hands and pieces of wood, into a being who called metal to his service.

Though the use of copper and bronze are known to go back several thousand years before the birth of Christ, yet the use of brass—a mixture of copper and zinc—is essentially of recent origin. In fact, the first brass known to have been made was produced sometime during the reign of Augustus between the years 20 B. C. and 14 A. D. One of the first examples of this material is in a coin which has been found to contain 17.31 per cent. of zinc. The method used in the manufacture of this product was to mix copper in the form of small granules or fragments with charcoal and calamin—a silicate of zinc hydroxid. This mixture was placed in a crucible and was very carefully heated for some time to a temperature sufficient to reduce the zinc in the ore to the metallic state, but not to melt the copper. The zinc being volatile, its vapor permeated the fragments of copper converting them into brass. The temperature was then raised sufficiently to melt the brass and enable it to be poured out of the crucible. This method was practised until the beginning of the nineteenth century and it was employed in one or two plants as late as 1850. It was gradually replaced, however, by the melting together of metallic copper and metallic zinc in crucibles of various sizes. This practice, in turn, continued until the past four or five years and is still very extensively employed both in this country and abroad. It is known essentially as the crucible process. Within the past ten or fifteen years oil-fired melting furnaces have come into use and just recently electric furnaces have begun to take their place in this field. In these latter furnaces, especially in combination with the adoption of economical pouring

arrangements, there have been tremendous savings in floor space and in labor charges, with no sacrifice and in most cases a decided betterment in quality. I predict that within the next fifteen years crucible furnaces for the melting of brass will be obsolete.

Looking back for a moment, however, we find that most of the brass made during the Middle Ages was produced in Germany. It was not until 1702 that brass was produced in England. In this country we know the beginnings of brass took place in the early part of the nineteenth century with the immigration of brass workers from England into the Naugatuck Valley, to Waterbury, and the towns in that general vicinity. Since then there has been a gradual spread of the industry westward, although the Naugatuck Valley still continues supreme as the brass center of the United States.

Before proceeding to a discussion of the properties of brasses under varying conditions, certain of the fundamental laws under which grain growth in metals may occur, as stated by Jeffries, will be presented. They are given in order that there may be a better appreciation of the conditions under which grain growth in its larger terms occurs.

"(a) On heating after cold plastic deformation. The term cold is here interpreted as meaning below the recrystallization temperature of the particular metal.

(b) On heating a hot-worked or annealed metal to a temperature higher than it had been previously heated, or heating it for a longer time at the same or at a lower temperature.

(c) On heating compressed metal powder to relatively high temperatures, but below the melting point.

(d) On heating or cooling a metal through an allotropic point, which occurs in a temperature region of grain growth and which is accompanied by a change in crystal form."

He furthermore states that the grain growth temperature of a metal in the solid state is confined to temperatures between that of recrystallization and the melting point and in most cases the lowest recrystallization temperature occurs at from 35 to 45 per cent. of the absolute melting temperature.

The recrystallization temperature is in most cases not a fixed temperature but is usually dependent upon (1) the amount of deformation, (2) the temperature of deformation, (3) the time

of heating at any given temperature, (4) the grain size prior to deformation. In general the recrystallization temperature becomes lower with an increase in (1), a decrease in (2), an increase in (3) or a decrease in (4).

Grain growth is of two types—normal and exaggerated. Normal growth occurs when the usual laws are obeyed; namely, that the grains become larger the higher the temperature and the longer the time of exposure. Exaggerated growth is that which we are particularly interested in and that to which the reference just previously mentioned applies. Some of the general laws which find applicaton in the case of both normal and exaggerated growth are briefly as follows:

1. As the size of a grain increases its attacking power increases.
2. As temperature increases, velocity of grain growth increases.
3. Segments of grains act as units.
4. The presence of strain gradients increases the tendency towards recrystallization.
5. The presence of temperature gradients increases the tendency towards grain growth.
6. The higher the germinative temperature—the temperature at which exaggerated grain growth takes place—the quicker the development of large grains.
7. The higher the germinative temperature the larger the grains.
8. The higher the temperature the shorter is the time required for recrystallization.

In the opening paragraphs of this paper it was stated that it might appear odd that one who has devoted so much time to the metallurgy of iron and steel should speak on the metallurgy of brass. If one will carefully examine the four fundamental conditions under which grain growth takes place it will be noted that heat treatment as so generally accepted—namely the heat treatment of steel—is based upon allotropy and is set forth in condition "d", above. As a matter of fact, the fundamental laws

of grain growth are more perfectly exemplified in the non-ferrous metals than in the ferrous field, around which centered the early developments in the constitution of metals.

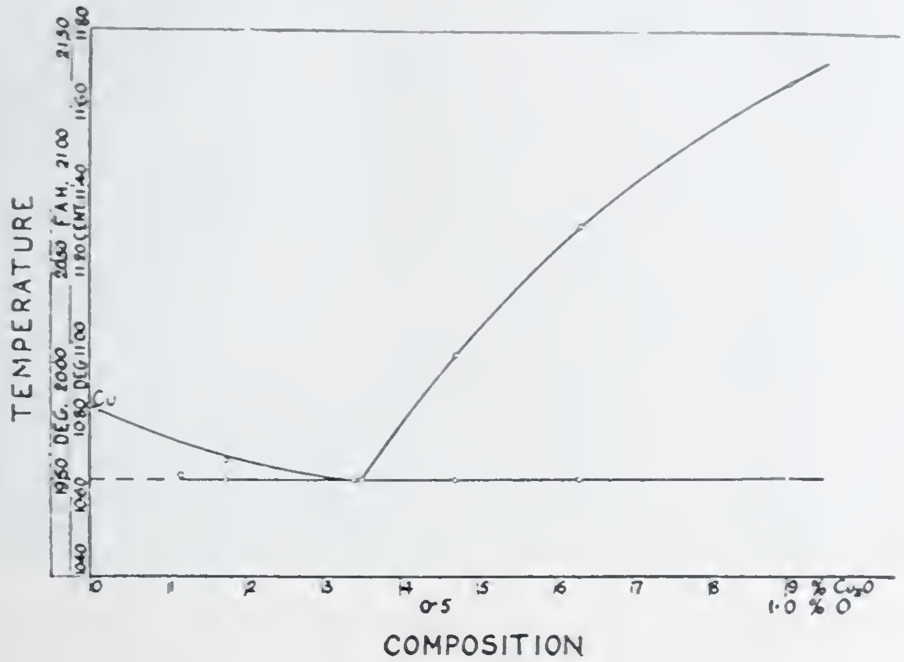


Fig. 1. Copper-Oxygen Equilibrium Diagram.

Before proceeding to a discussion of brass let us turn to copper. It is normally realized that copper of high quality can be procured. From an exact standpoint one can purchase copper with a purity of at least 99.88 per cent. The major impurity in copper is oxygen and by an examination of Fig. 1 it may be noted that with 3.5 per cent. Cu_2O or approximately 0.39 per

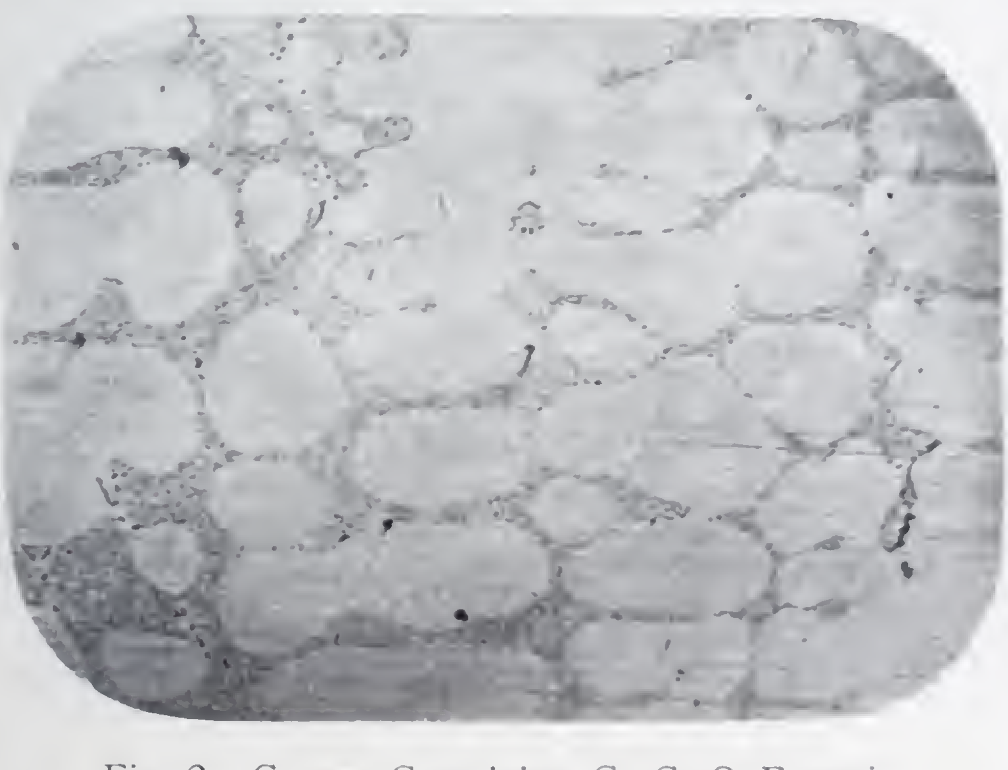


Fig. 2. Copper Containing Cu-Cu_2O Eutectic.

cent. oxygen there would be a eutectic made up of copper and Cu_2O. The normal definition for a eutectic is an alloy of lowest melting and by examining this chart it is noticeable that whereas the melting point of pure copper is 1083 degrees C. the melting point for this eutectic is approximately 1065 degrees C.

The effect of this eutectic is set forth in Fig. 2. In this case but 0.04 per cent. of oxygen is present producing 0.365 per cent. cuprous oxid, resulting in about 10 per cent. of the area becoming eutectic; thus the effect of even small traces of oxygen is especially noticeable.

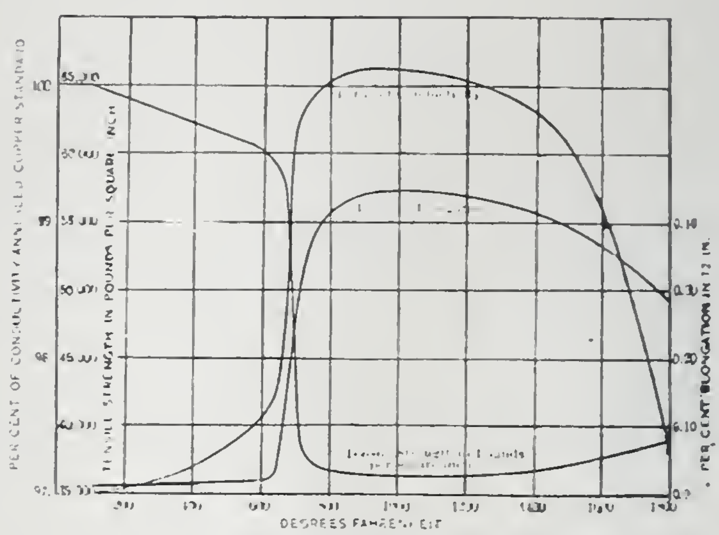


Fig. 3. Variation of Physical Properties of Copper Wire with Variations of Annealing Temperature.

In Fig. 3 is given the composite tabulation of the results of physical tests on copper wires which, after having been hard drawn were annealed at various temperatures. It is noticeable that when the copper is in the hard-drawn condition its strength is the greatest and its elongation and conductivity are the lowest.

This continues until there is reached a temperature lying between 600 and 800 degrees F. at which temperature range the elongation and conductivity undergo a marked increase, and the tensile strength a marked decrease. There is no appreciable effect on the tensile strength at succeeding higher temperatures up to 1800 degrees F. Up to 1400 degrees F. the same general condition is true in the matter of elongation. Above 1400 degrees F., however, there is a marked falling off in this property. The same general conditions hold true with regard to conductivity. The decrease in tensile strength between 600 and 800 degrees

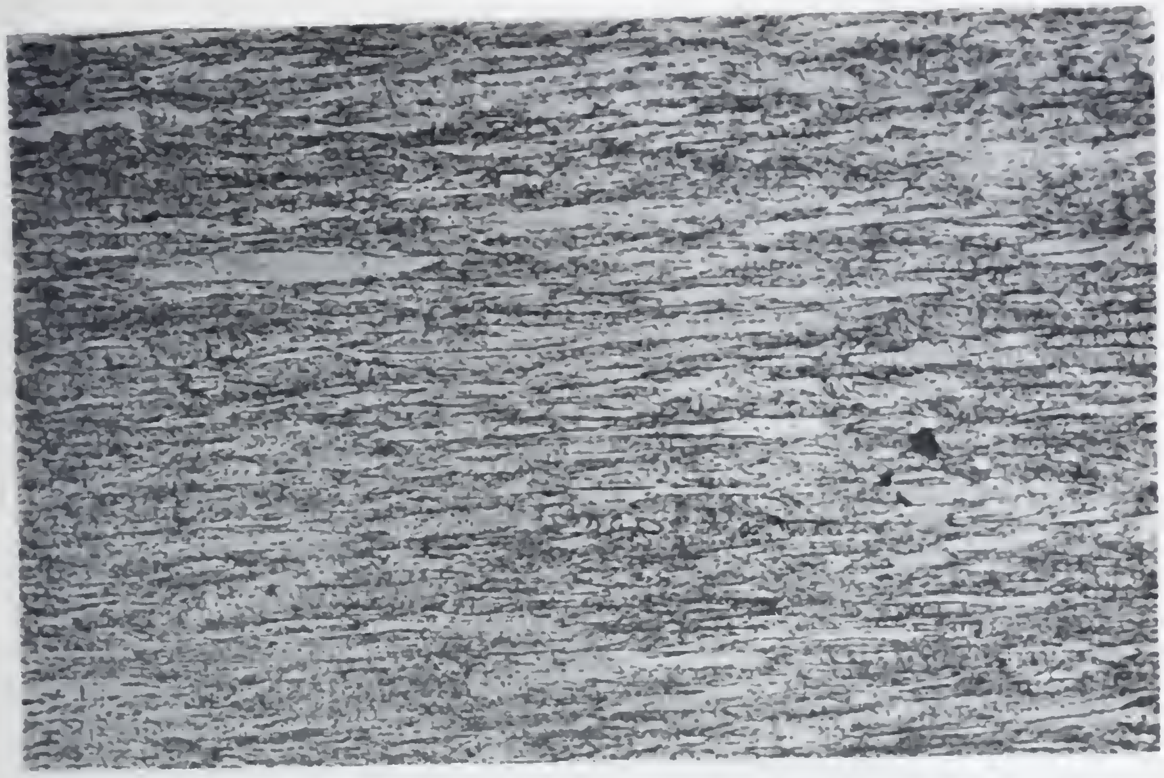


Fig. 4. Hard-Drawn Copper Tubing. Magnification 75.

F., combined with the corresponding increase in elongation and conductivity, is due to the influence of recrystallization and the production of crystalline material at the expense of amorphous or non-crystalline material. The marked decrease in elongation and conductivity at temperatures above 1400 degrees F. is due to the large grain size. The results of the annealing so strikingly

Fig. 5. Copper Tubing Annealed at 200 Degrees C.

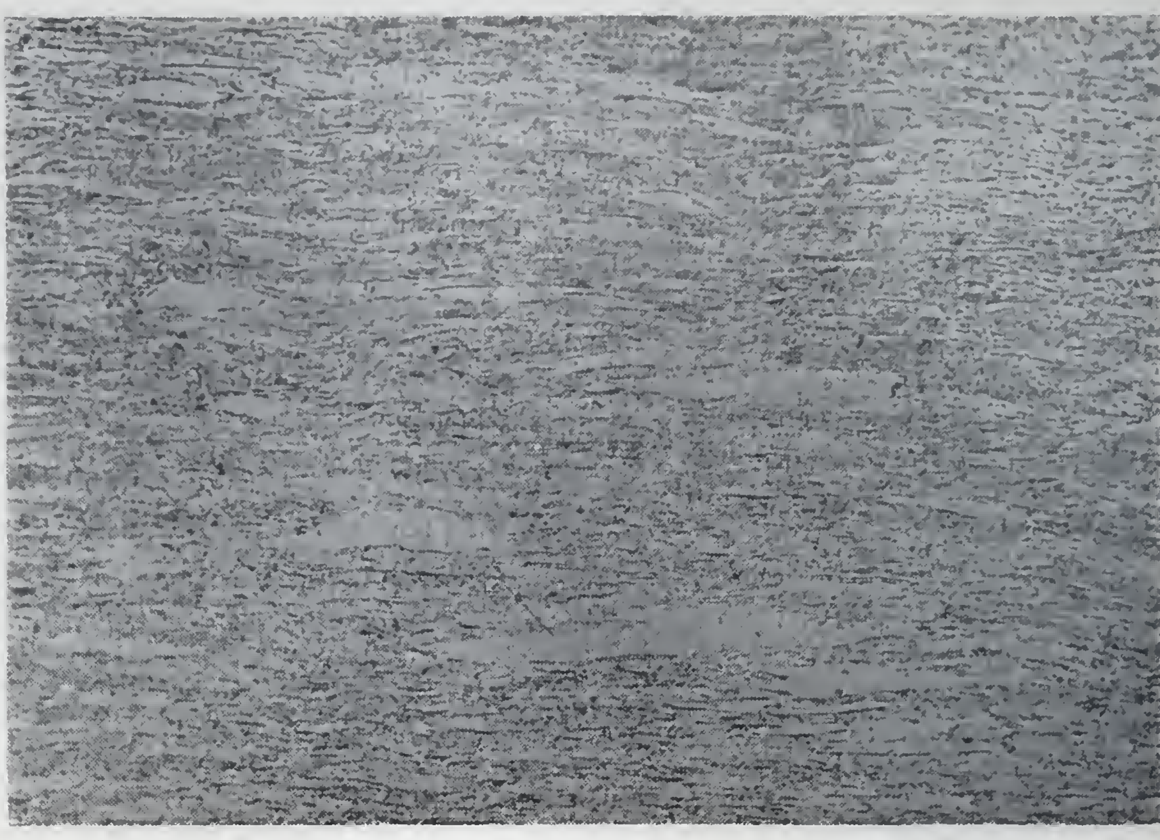


Fig. 6. Copper Tubing Annealed at 300 Degrees C.

given in Fig. 3 are equally well shown in a series of photomicrographs, Fig. 4-8, setting forth the changes which take place in the micro-structure of cold-drawn copper when annealed at suc-

Fig. 7. Copper Tubing Annealed at 400 Degrees C.

cessively higher temperatures. Fig. 4 is of a hard-drawn copper. The strain lines are decidedly noticeable.

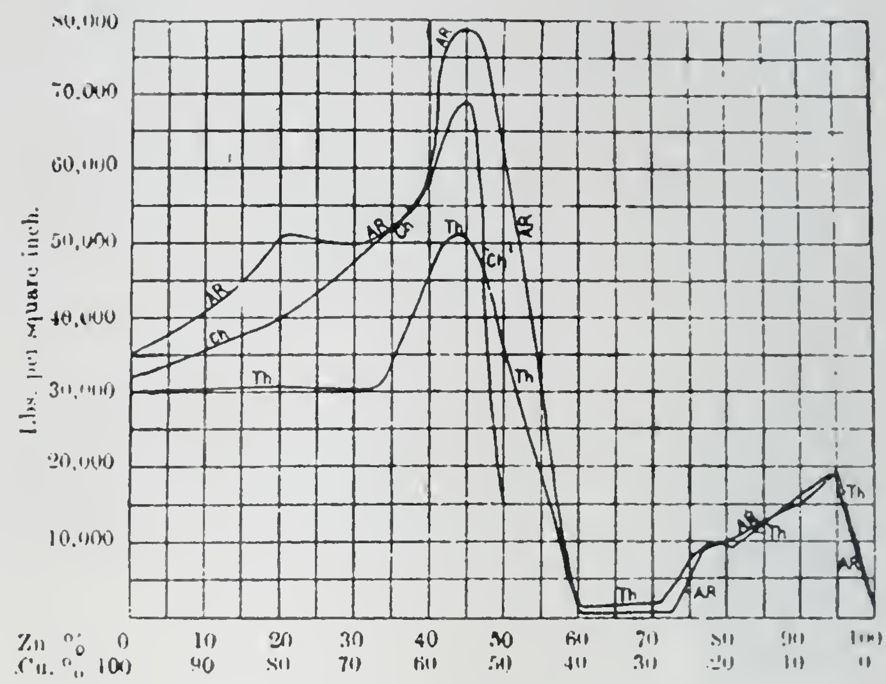
Fig. 5 shows the conditions brought forth by an annealing at 200 degrees C. No appreciable change is noticeable.

Fig. 6, taken from copper annealed at 300 degrees C., bears evidence of recrystallization. The same is also manifest in the figures giving the effects of the anneal at 400 degrees C. and 1000 degrees C. Equiaxed crystals are first manifest at 400 degrees C. and these increase in size with the increasingly higher temperatures.

Fig. 8. Copper Tubing Annealed at 1000 Degrees C.

A full appreciation of the laws of grain growth combined with a thorough understanding of the constitutional diagram for the copper-zinc alloys would enable considerable prediction with regard to what can and cannot be done for the brasses by heat treatment. As a matter of interest there are no commercial brasses produced with less than 55 per cent. of copper. An examination of Fig. 9 and 10 indicates the reasons for this condition. Alloys with less than 55 per cent. of copper have practically no strength, whether the metal be in the cast or the rolled condition.

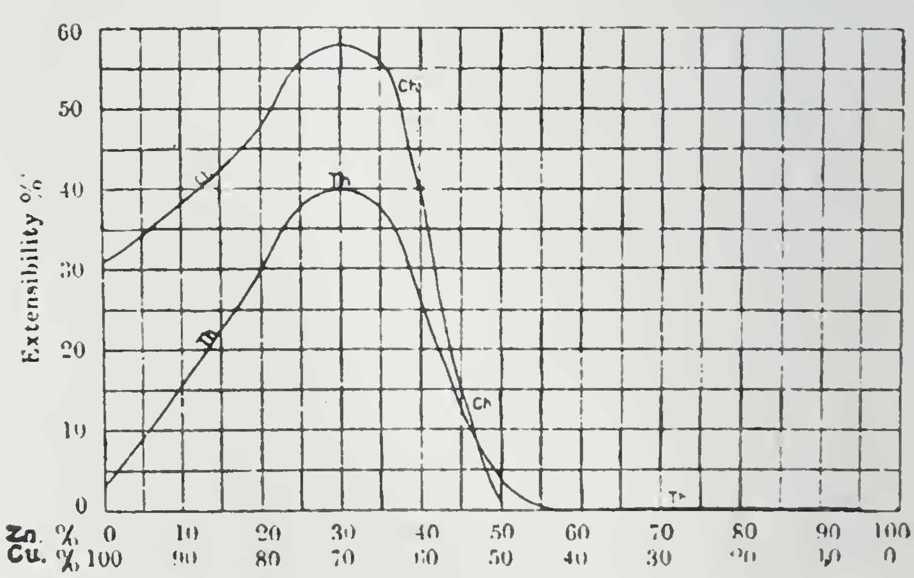
Fig. 9 gives the results of three investigations on this matter —one conducted by Thurston on cast brass, one conducted by Charpy on worked brass and one conducted by the Alloys Research Committee, also on worked brass. It is noticeable that all



A. R.—Alloys Research Committee (Worked Rods) Th—Thurston (Castings) Ch—Charpy (Annealed Brass)

Fig. 9. Tensile Strength of Copper-Zinc Alloys.

three authorities obtained as the brass of a maximum strength an alloy consisting of 55 per cent. copper and 45 per cent. zinc; and that with succeeding quantities of zinc there was a very sharp falling off in the tensile strength. In the matter of ductility,



Ch—Charpy (Annealed Brass) Th—Thurston (Castings)

Fig. 10. Ductility of Copper-Zinc Alloys.

as set forth in Fig. 10 from results obtained by Thurston and Charpy, the alloy with the maximum value consisted of a 70-30 mixture, and with more than 30 per cent. zinc the reduction in the ductility was marked. With 50 per cent. of zinc the ductility was practically zero.

Looking at the brasses from a constitutional standpoint one observes from an examination of the copper-zinc constitutional diagram (Fig. 11) that the copper and zinc are united to form

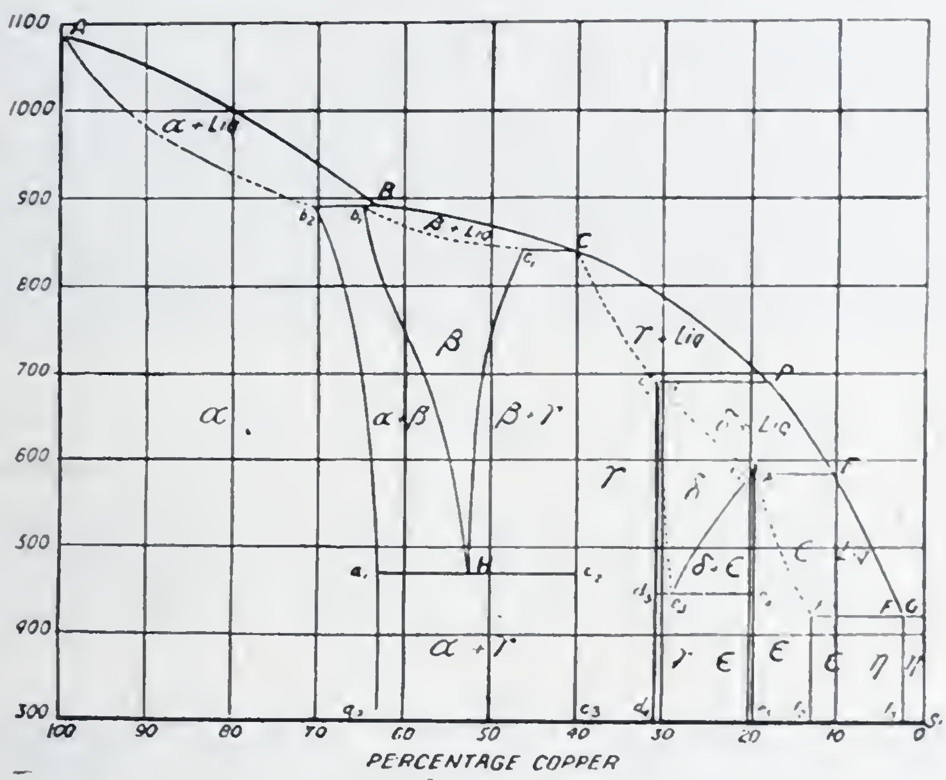


Fig. 11. Copper-Zinc Constitutional Diagram.

a solid solution with all proportions of zinc between a mere trace and approximately 37 per cent.; further, that with between 37 and 48 per cent. of zinc the constituents that should be expected are the alpha and beta. To be sure, the diagram gives at the lower temperatures alpha and gamma but the gamma is procured only by a long annealing and is seldom if ever present in commercial products.

The term solid solution has been employed. This implies practically the same status for metals as one gets in the case of a liquid solution. The phenomenon of sugar dissolving in water or salt dissolving in water is so common that we see nothing strange about it. In the same manner it is quite possible for two metals such as copper and zinc to dissolve in one another.

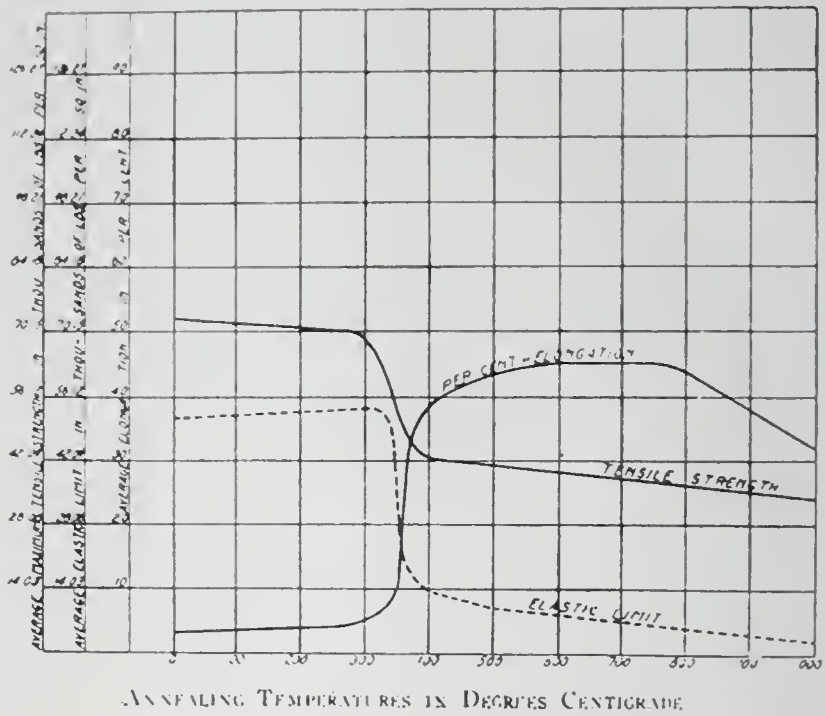


Fig. 12. Effect of Heat Treatment on the Physical Properties of Brass 90 Copper, 10 Zinc.

If we can but adjust our viewpoint there should be nothing peculiar about this behavior. Thus, when copper and zinc dissolve in one another to give zinc concentrations between a trace and 37 per cent., the product resulting is an alpha solid solution. If there is more than 37 but less than 48 per cent. zinc then there are two solutions usually present in commercial brasses within

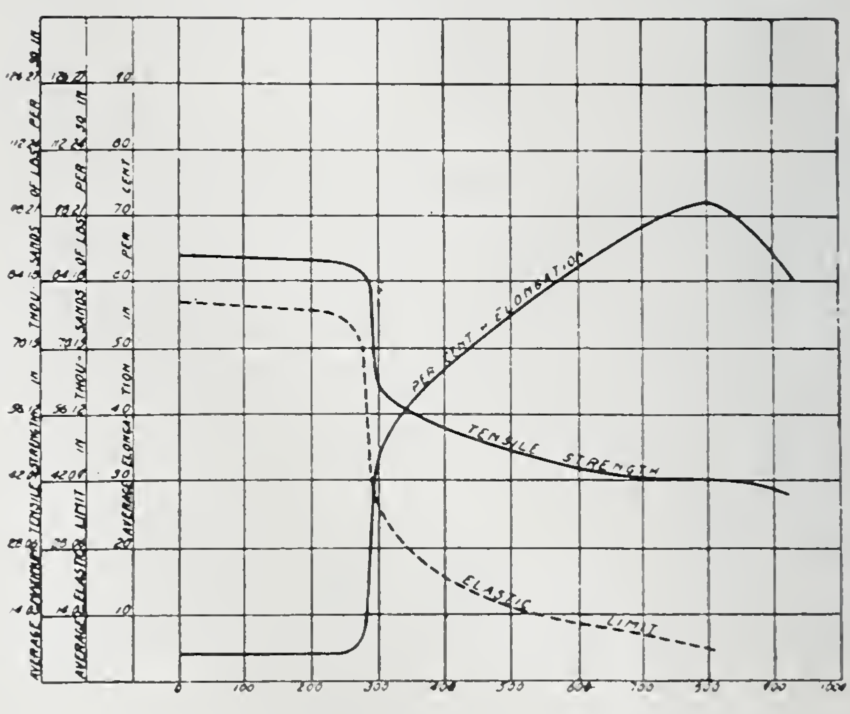


Fig. 13. Effect of Heat Treatment on the Physical Properties of Brass 67 Copper, 33 Zinc.

Fig. 14. Hard-Drawn Brass Tubing (70-30). Magnification 75.

this composition range. One of these is an alpha and the other a beta solid solution. Each of these concentrations has slightly different physical properties, and the photomicrographs reproduced

Fig. 15. Brass Tubing (70-30) Annealed at 300 Degrees C.

below show these different constituents and the way in which they react to heat treatment.

Before proceeding to that matter, however, there is set forth in Fig. 12 the effect on the physical properties of annealing cold-drawn brass consisting of 90 per cent. copper and 10 per cent. zinc at successively higher temperatures. Fig. 13 further shows the effect of annealing cold-drawn brass consisting of 67 per cent. copper and 33 per cent. zinc. It will be noticed that these figures exhibit characteristics similar to each other and similar to those shown in Fig. 6 (copper) though there may be slight differences as to temperature at which recrystallization takes place and differences, not of kind but of amount, as to tensile strength and elongation.

Fig. 16. Brass Tubing (70-30) Annealed at 400 Degrees C.

The next series, Fig. 14-18, represents the conditions of grain structure in a 70-30 mix. Fig. 14 is from metal in a hard-drawn condition. The parallel bandings in the crystals are strain lines and indicate cold working. These will be found to persist through certain of the lower annealings. Fig. 15 shows the effect of annealing at 300 degrees C. It will be noted as we progress that the first striking evidences of recrystallization are

Fig. 17. Brass Tubing (70-30) Annealed at 500 Degrees C.

in those samples which were annealed at 400 degrees C. Recrystallization is very much in evidence in the photomicrograph taken from metal annealed at this temperature. It is also pres-

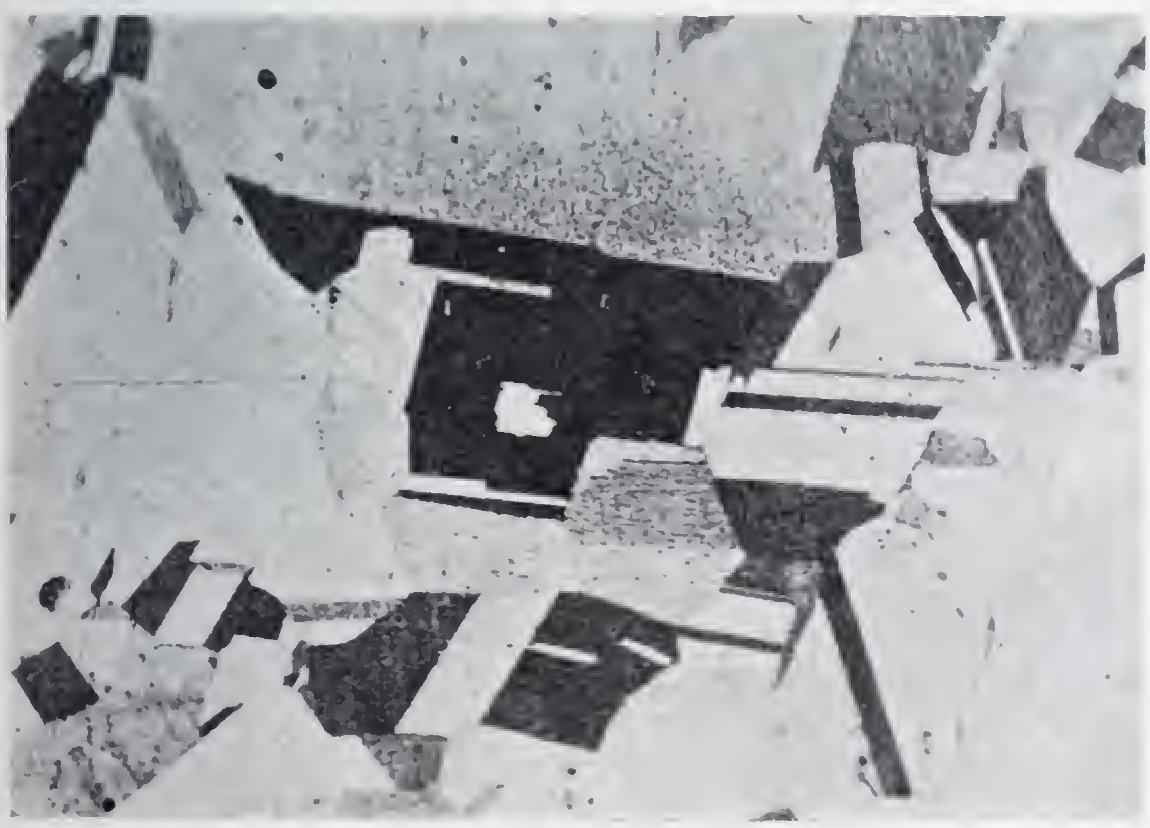


Fig. 18. Brass Tubing (70-30) Annealed at 900 Degrees C.

Fig. 19. Hard-Drawn Brass Tubing (60-40). Magnification 75.

ent in all photomicrographs taken from metal annealed at temperatures above 400 degrees C., with a noticeable increase in grain size in the case of those specimens annealed at the higher temperatures.

Fig. 20. Brass Tubing (60-40) Annealed at 300 Degrees C.

The effect of heat treatment on cold-drawn tubing containing 60 per cent. copper and 40 per cent. zinc is further presented in Fig. 19-23. The recrystallization changes which occur are in general identical to those discussed under the 70-30 mix. The dark grains are the beta constituents. It is observable that at the lower annealing temperatures, strain is present and that at above 300 degrees C. this disappears. Also, at the higher temperatures it is noticeable that there is a distinct change in the general characteristics besides that of grain enlargement. This is essentially the resultant of absorption of the alpha constituent by the beta.

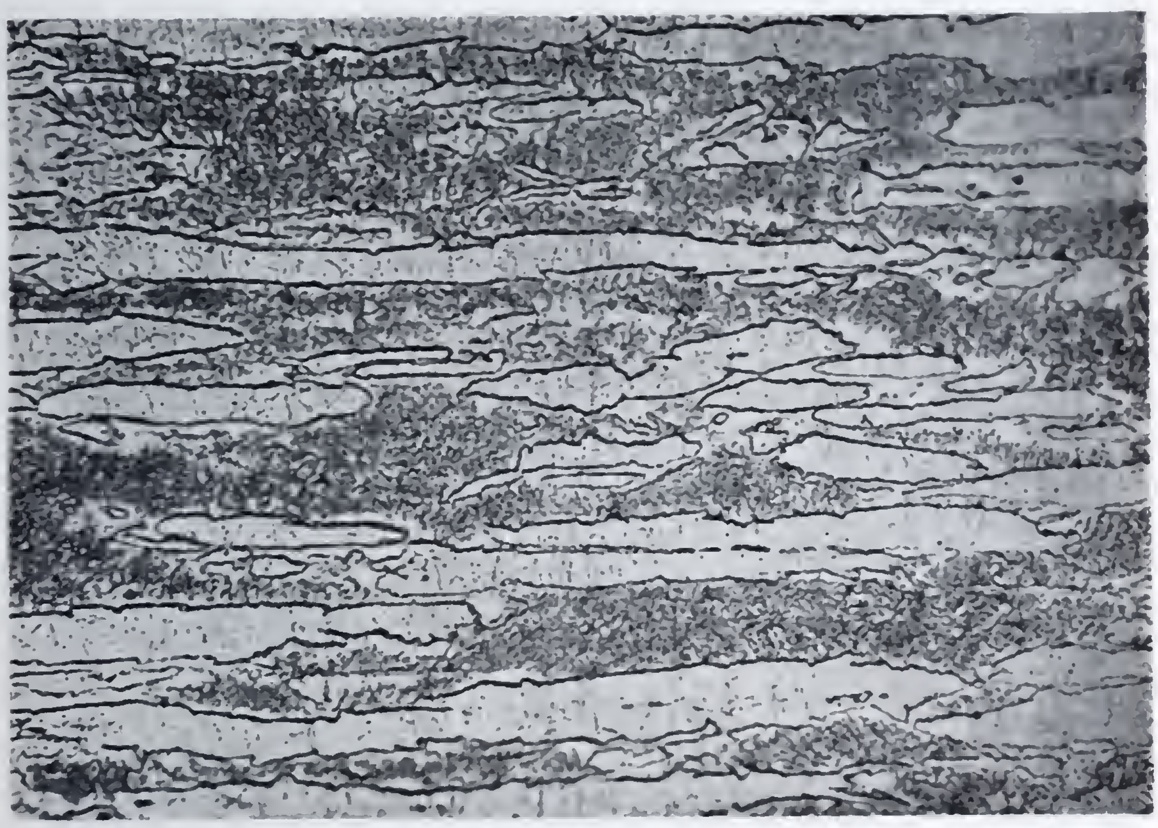


Fig. 21. Brass Tubing (60-40) Annealed at 400 Degrees C.

For your further consideration, in Fig. 24 there is presented one photomicrograph from what is said to be a manganese bronze. Essentially it is a manganese brass. Its composition is 62.04 per cent. copper, 0.58 per cent. tin, 33.27 per cent. zinc, 0.83 per cent. lead, and 0.22 per cent. iron. It is a cast product, the black being beta, the light alpha. Under physical test it was shown to possess 25,000 pounds per square inch elastic limit, 57,000 pounds per square inch tensile strength, 46 per cent. elongation in one inch, and 48.4 per cent. reduction of area.

Fig. 22. Brass Tubing (60-40) Annealed at 500 Degrees C.

If there is any one thing which it is desired that you carry away with you to-night it is the tying up of the constitutional diagram, the physical test tables, and the photomicrographs. In the cases of the copper the 70-30, and the 60-40 mixtures, the metal

Fig. 23. Brass Tubing (60-40) Annealed at 800 Degrees C.

started with was in a cold-drawn state. It underwent annealings at successively higher temperatures. These annealings converted the amorphous material, which in itself possesses high tensile strength and little ductility, into a crystalline material which possesses lower strength and higher ductility; thus, as the tensile strength decreased and the elongation increased, the crystalline changes were a decrease in strain lines, proceeding

Fig. 24. Cast Manganese Bronze. Magnification 75.

into recrystallization and this in turn developing in appreciable grain growth. All of these changes are characteristic in brasses, characteristic in pure metals, and if we can forget allotropy—which is one of the special properties inherent in steel, especially steel with appreciable quantities of carbon—we would find that these same conditions are peculiar to steel. As a matter of fact those conditions which in the steel industry, especially in the sheet metal industry, have for long years been looked upon as diseases are in reality but normal manifestations of the laws of grain growth.

DISCUSSION

Mr. D. D. Pendleton:* I have listened with a great deal of interest to Dr. White's paper on the nature of brass, and am exceedingly glad that he has given so much time in particular to condenser tubes.

Here in Pittsburgh surface condensers have in the past almost been condemned before they were tried. In fact, some of our local engineers advocate the use of surface condensers on the Monongahela above the mouth of the Youghiogheny River "hardly ever"; below the mouth of the Youghiogheny River "never"; and on the Ohio and Allegheny Rivers "sometimes". Surface condensers are coming to be recognized as most important in power-plants, and I think that this paper will give us all something to think about, particularly some of us who are selling and using surface condensers in the Pittsburgh district.

Several years ago, our chief chemist, Dr. G. C. Holder, issued a pamphlet discussing condenser tubes, and the method of obtaining data relative to their failure, and I should like to bring out certain points which he advocates.

We agree with Mr. White that it is absolutely necessary to study all conditions. Our idea is to bring out some points which are very salient in order to complete any data relative to condenser tubes and their failure. In order to do that, we must call on the person who comes in contact with users to supply us the necessary information. Even then, it is sometimes difficult and almost impossible to arrive at a definite conclusion, but the attempt is a step forward and that means progress. It is an acknowledged fact that one alloy is not suitable under any and all conditions, and this has caused consulting engineers to be brought in to study conditions and make recommendations accordingly.

Engineers are prone to look too lightly upon water conditions. Water, which is a cooling medium used in a condenser, varies as to composition, physical characteristics, etc., according

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to seasons of the year, and we do know that certain alloys do withstand corrosion under certain conditions better than others. Condenser tube failures are not generally, I believe, the fault of the manufacturer, and I venture to say that 95 per cent. of the failure of tubes is entirely due to local conditions. The faults of manufacture are in the majority of cases apparent in the process of manufacture. In the failure of condenser tubes, too much has been taken for granted. Defects are blamed on the manufacturer or failure is taken as a matter of course.

The three important steps in the manufacture of wrought brass are good casting, shop supervision, and good annealing control. Not all corrosion problems are alike and in order to classify them intelligently it is perhaps necessary to follow them from certain periods.

Since water is the medium used it is naturally necessary to procure some information regarding it, which includes:

1. Information as to supply of water—whether fresh, salt or brackish, or whether cooling tower is used.

2. Mechanical analysis of water, pertaining to suspended matter.

3. Whether tubes are choked with solid matter, and nature of this material.

4. Speed of water.

5. Arrangement of baffles and steam distribution.

In studying a tube which has failed and is removed from a condenser, it should be carefully marked to distinguish the top from the bottom as it was in service. The record should further indicate the direction of water flow; the position of sample from the length of tube and whether near the support plate; the length of service of the corroded tube; the length of the tube; the nature of the deposit in the tube (which should be protected by plugging both ends of the sample); position of the tube in the condenser, and whether corrosion has been evident on any other part of the condenser; if a plant has more than one outfit, whether corrosion appeares only in one or in all of them; whether tube failures are more prevalent at different seasons of the year.

Some of these queries may seem irrelevant, but each serves its purpose. Take, for instance, the cooling tower. The use of the cooling tower causes a concentration of salts, thereby making the water more corrosive.

The mechanical analysis of water relative to suspended matter is important, because suspended matter of varying specific gravity will settle in the length of the tube, and it is to the action of some of this inert material that local corrosion is ascribed.

As to prevention of corrosion by dezincification, about the only suggestion is the frequent cleaning of condenser tubes. The formation of an oxychlorid zinc salt appears to produce a scale that acts as a catalyzer, freeing the chlorin from the salt contained in the water, which quickly attacks the brass. A second method is the "Cumberland" system of protection, which system has been tried in England—in some cases with a great degree of success and in other cases with less. In any case, it is important to install the system before corrosion starts in the tubes. The system consists in placing iron electrodes in the water ends of the condenser and connecting them to the positive pole of a direct-current dynamo. The iron electrodes are insulated from the vessel to which the negative pole of the dynamo has been connected, so that current flows from the electrodes to the walls of the tubes. A pressure of eight volts is generally used with a current density of two to three amperes per 1000 square feet of surface, although under certain conditions a density of 10 amperes has been used when first installed and generally reduced to two or three amperes. By this means, oxygen is set free at the iron electrodes and hydrogen on the surface of the tubes. This means that corrosion is confined to the iron electrodes, which can be replaced at small cost.

Tubes generally have three layers of material in structure—inter-crystalline material; crystalline material; and structureless surface layer. These layers are the reverse in their resistance to corrosion. This is apparently due to higher copper content in the surface layer, and this difference in shells amounts to about one-half per cent. between the copper content of the inside

and the outside. It is this coppery layer which leads the manufacturers of the "Bemal" tube to make assertions regarding its resistance to corrosion.

After knowing the conditions under which the tubes are to function, we are in a position to suggest to better advantage the alloy to be used. "Muntz" metal should be used only in contact with fresh water.

Seventy per cent. copper and 30 per cent. zinc appears to be satisfactory in ordinary sea-water at temperatures below 122 degrees F., but at higher temperatures or with estuary waters it is not satisfactory.

Crystal grains seem to have ingratiated themselves into the minds of some engineers, but it is extremely doubtful whether they can define why they desire such and such a grain size. Personally, we do not place much confidence in grain size other than designating a minimum grain size.

If the prospective purchaser has no consulting engineer, his principal effort should be confined towards putting matters in the hands of a manufacturer who will give him honest working and annealing of tubes. Any manufacturer of proper standing will be glad to submit samples and photomicrographs of his product, and if these conform to the proper standards, the purchaser should be amply protected.

Mr. T. D. Lynch:* We have heard to-night a paper of which we ought to feel very proud. It covers the subject in a broad and thorough manner. The pictures, showing the melting ranges were very interesting to me and I am sure to many others. When we realize that there is a great variety of opinions given as to the melting points of different metals, the curves give a good explanation of why one man will give you the temperature at which a metal solidifies, and another the temperature at which it becomes liquid, and the range between gives the variation for the different compositions. These curves show up at this point very plainly.

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Brasses, bronzes, and copper are given to us in two different forms, cast and worked. The cast form is the one that must be made first. If we are going to work it, it must be cast into ingots. But the working, consisting of rolling, extruding or drawing, causes the brasses to harden more quickly than the ferrous metals. The art of hardening copper is found only in working the copper or by alloying it with other metals; we have no trouble in hardening copper by work and by alloying. We often hear of some one finding the long-lost art of hardening copper but the hardening of copper without work or adding something to it in the form of an alloy is a myth.

The annealing curves shown are very interesting and very much to the point. Several years ago in working on this problem with one of the big brass manufacturers I was in the laboratory of their metallurgist and he showed me curves similar to those we have seen to-night. For every alloy he made he had worked out similar curves, not for publication but for his own personal use. He showed them to me and I considered it a great favor to see such curves, and it gave me a better idea than I had ever had before of the effect of heat on the non-ferrous alloys. In addition to the curves he also had microphotographs of the metals at different temperatures.

At one time we had a great deal of trouble with phosphor-bronze wire. It would snap off while in stock, caused by cold drawing or cold working leaving the internal stresses that caused it to go to pieces. We found that heating to the low temperature of 200 degrees C. will relieve the stresses and prevent the material from breaking. The simple operation of "cooking" or of heating to 200 degrees C. for two hours, renders the material practically free from internal stresses and yet does not appreciably reduce its physical properties.

The curves just noted give a good explanation of why this occurs.

We are indebted to Mr. White for his most admirable paper.

Mr. Max Hecht:* A survey of the literature indicates that a vast amount of effort has been applied in the manufacture of cartridge cases. Can any of the data be applied to the problem of condenser tubing?

Engineers in power-plant practice are turning to condensation of steam, and utilizing the condensate for steam generation. Condensers are installed both on the seaboard and in unpolluted fresh-water supplies, with gratifying success. The question of metal composition for tubing is one on which considerable thought must be placed, and I am aware that every large user of condenser tubing is making a study of what metal to use—admiralty, 70 per cent. copper and 30 per cent. zinc, "Muntz" metal, or pure copper.

Prior to 1912, I do not believe that surface condensers were installed in the Pittsburgh district, due to the polluted water-supply. A plant scale experiment was attempted in one of the large steam plants, applying various metal composition tubing in the various surface condensers. The installation included:

One shell fitted with admiralty tubes—70 per cent. copper, 29 per cent. zinc, 1 per cent. tin.

One shell fitted with brass tubes—65 per cent. copper, 35 per cent. zinc, tin coated on both surfaces.

One shell fitted with brass tubes—65 per cent. copper, 35 per cent. zinc, tin coated on the inner surface.

One shell fitted with copper tubes—99.8 per cent. copper.

Shells fitted with "Muntz" metal tubes—60 per cent. copper, 40 per cent. zinc.

After seven years operation the replacement of tubing was found increasing in the following order—admiralty, copper, brass, "Muntz" metal.

Very little tin was noted on the tin-covered tubes. Other than periodic cleaning of condenser tubes for economic operation, no mechanical work was done on the tubing.

*Chief Chemist, Duquesne Light Co., Pittsburgh.

The water-supply available is the Ohio River, receiving the varying flows of the Allegheny and Monongahela Rivers. The plant in question is located about 2½ miles below the head of the Ohio. This supply contains all the industrial and domestic waste of the entire watersheds of both rivers, and varies in its content of free acids, depending upon the volume discharge of the rivers. I believe there is a surface condensing plant on the Monongahela River between Lock 1 and the Point, but no information can be offered as to the successful use of metal in condenser tubing.

To sum up, we have a fresh-water supply in the Pittsburgh district, polluted with mine and industrial waste, and with sewage. Can the tube manufacturer control his product, and produce tubing with the lowest practical copper content—physical qualities considered together with proper grain size—which will give sufficient length of service, or must the user make a greater initial investment and use tubing with the higher proper content to keep away from leakage, particularly in this district?

Mr. A. E. White: I wish I could answer that question. I am rather definite in my feeling that under no consideration should we use 60-40 tubes in the Pittsburgh district. I think we ought to use either 70-30 or 70-29-1. By 60-40 I mean 60 per cent. of copper and 40 per cent. of zinc, and by 70-29-1 I mean 70 per cent. of copper, 29 per cent. of zinc and 1 per cent. of tin. When you have 60 parts of copper and 40 of zinc you have an alloy made up of two different constituents. You have, thereby, the two poles necessary in an electrical circuit with an accompanying strong probability that an electrical current may be set up, thus producing corrosion. With a 70-30 composition you have only one solid solution.

In the Pittsburgh district I would recommend a rather strict adherence to proper grain size, for the reason that with the grains of different sizes there are again established two poles leading to the same trouble as just indicated. Also, the grains should in all cases be small. I believe one can to-day buy from manufacturers tubes in which grain sizes, at a magnification of

75 diameters, would not exceed one-half inch. When material of that type can be procured it is unwise to get material with varying grain sizes.

A 70-30 tube has merely one constituent. A 70-29-1 tube has only one constituent. The supposed advantage of tin, briefly stated, is due to the oxid formed over the surface of the metal. This acts as a paint, thereby preventing corrosion from proceeding further. Whether or not it is possible for the water in the Pittsburgh district to dissolve that oxid I am not prepared to say, but I am very definite in my opinion that I would not wish to see any 60-40 tubes in the Pittsburgh district, and I would specify either 70-30 or 70-29-1. If prices were the same I would use 70-29-1.

MR. W. J. MERTEN :* I would like to ask the speaker whether the sequence of the annealing temperature cycle and the results obtained apply to manganese-bronze castings, and I would also like to ask what is the effect of small percentages of tin in brass with reference to the annealing temperatures as determined by him and given in this paper.

The tin has appreciably little effect on the annealing temperatures, at least within the limits commercially used. Most of the manganese bronzes are not products which are mechanically worked, but rather are products which have undergone no mechanical working; that is, they are castings. You have grain sizes which are too large, and in order to change this again you would have to go to the first law of a higher temperature. The higher temperature is a liquid state and therefore you get no appreciable change. Heat treatment on metal in such a state would have no effect on grain size. To be sure, there are internal strains due to the different rates in the cooling of different parts of the casting. Annealing is good to relieve those strains, but annealing does not play any part with relation to change of grain size.

Isn't there a decided influence of the rate of cooling from the liquid to the solid upon the distribution of the alpha and beta constituents of the manganese bronze?

*Research Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Mr. A. E. White: Yes, very probably. Of course your casting, as you produce it, is cooled slowly and if you had it above that horizontal line that was shown in the chart and quenched it in water or cooled it faster, you might retain added quantities of the beta constituent.

Mr. D. D. Pendleton: I would like to ask you if in your experience you have found any advantage from tinning, other than the temporary protection from corrosion, and possibly the protection of the tube from erosion?

Mr. A. E. White: I have had little experience in the matter of tubes that have been tinned, but the little I have had does not indicate any great advantage in tinning the tubes.

APPRAISAL OF OIL AND GAS PROPERTIES

By Roswell H. Johnson*

The business of oil production consists in buying an unknown amount of oil to be produced at an unknown cost and to be sold at unknown times at an unknown price. This is true whether producing wells or undrilled lands are bought. The difference lies in that the probable error is much greater in the latter case. The essence of the oil business, then, consists in the determination of these unknown quantities with the least possible error. That is to say, the cost of production, the time at which the oil will be sold, the price at which it will be sold and above all the amount which will be sold must be estimated, and, from these estimates, the sum that one should pay to obtain the property is to be determined. Is it not evident, then, that appraisal is the very core of the oil and gas business?

In many other businesses, success in reducing cost is a main consideration. In this business, the question of more or less cost of maintenance is far less important than the question of the amount of oil to be produced, owing to the fact that small wells cost almost the same as large ones, both to drill and to operate, and that the variation for any one type of well is not great. While the truth of this statement would seem obvious, it is nevertheless a fact that many operators determine the price at which they will buy a property merely on the basis of what others pay, being content merely to conform or to imitate. This unbusiness-like procedure is disguised so as to seem a more helpful process than it really is, by the method of establishing a unit of the "barrel day"; that is, the number of barrels produced by the property per day is multiplied by this unit to determine the value of the property. It is, of course, obvious that such a course merely takes a price that has been paid in the past and assumes that the purchasers paid a proper

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value. It evades true appraisal. The successful executive is, of course, concerned in finding how much this current price *differs* from a sound price. Knowledge merely of the current price gives him no proper guide as to whether a certain property should be bought, nor does it indicate the field in which it would be most profitable to make purchases.

A second substitute for true appraisal on the part of some operators is the rule to pay as much for a property as will be received for the oil in a certain length of time, based on the assumption, of course, that a certain percentage of the total ultimate amount of oil will be produced in that time. Notice that this is not expressed in money, but in time, and that this time represents merely an opinion that such a proportion of oil will be produced during this period, and that such a proportion of the total revenues constitutes a proper value of the property. Such a method cannot be considered true appraisal, and it retards the progress of the art of appraisal.

True appraisal of oil properties is relatively new. It was first utilized on an important scale, so far as known to me, in the California fields. The method was adapted from the mining industry; a mining engineer, Mr. M. L. Requa, playing an important part in the development of the methods in these early appraisals.

True appraisals, based upon the returns which a property will make, fall under two heads—the volumetric method and the production-curve method.

In the volumetric method an estimated profit for each barrel is first calculated and it is at this point that one of the greatest weaknesses of the volumetric method appears, because the profit per barrel differs so greatly, depending on the time when the barrel is produced and on the size of the well. With this figure in mind, the volume of the pay and its porosity is determined. From the volume of voids thus calculated, with the deduction of a percentage which it is supposed does not contain oil, and with a further deduction of the percentage of oil which is supposed not to be extractable by the method that will probably be employed, the amount which is to be extracted is calculated.

This amount, times the profit per barrel, equals the undiscounted value. This value, however, cannot be rationally discounted to obtain present worth because no production curve is used from which to ascertain the date at which the oil will be produced.

From the work of Chambrier* in the Alsatian fields—which do not seem to be peculiar in the nature of their oil sands—it has been found that only 17 per cent. of the oil was extracted by the ordinary methods. It is because of the importance and uncertainty of this deduction for non-extractability and because of its weakness in the matter of compound discount that this volumetric method has very nearly fallen into disuse.

This brings us, then, to the production-curve method, or as it is sometimes called, the annual analytic method. This method is to ascertain the yield in each future year, the cost for each year, and thus the profit for each successive year. The profit of each year is then separately discounted and is then added to obtain the present value of the expected profit. To the result will be added the discounted salvage value. It does not seem possible that a rational value can be obtained with any less labor than this.

The purpose of this paper is to urge the wide practice of this method. The reason why this method was not practised earlier than it was, was the general feeling that the uncertainty of production was so great that a curve of its future history could not be drawn within sufficiently reasonable limits of error. The collection of very many production curves has now shown, however, that the production curve is far more systematic than was supposed. In fact, a curve can be drawn according to one formula that will give an appraisal value much more closely than any other method can give to the actual value as eventually disclosed. The discovery by Lewis and Beal that this curve is so near a hyperbola has been the most important step forward in appraisal since the work of Requa.

Given the history of three or four years of any particular

*"La Source de p trole jaillissante de Pechelbronn," by Paul de Chambrier. (In Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1920, v. 132, p. 458-463.)

well, its future can now be constructed by graphically extrapolating the line on the theory that it is a hyperbola, as described in the "Manual for the Oil and Gas Industry"* which is issued by the Treasury Department. If a shorter record is available, a shorter time unit such as half years, quarters, or even months may be employed, although the error is, of course, thereby somewhat increased. The greatest difficulty about this lies in the fact that individual well histories are not readily obtainable, so that generally one merely has the history of the production of a lease. In the earlier years the number of wells on the lease is increasing, so that the average well is not the same thing but is itself changing until all are drilled, and in the very late years we find the selective abandonment of well after well, which again changes the make-up of the average well. Therefore, it is not until the wells on the lease and those on the adjoining leases have been drilled that the production curve is regular; and then it ceases to be, when abandonments begin. It is probable that henceforth the records of individual wells will be kept very much more frequently than in the past to make more accurate appraisals possible.

Where sufficient history of any one well is not known so that the curve can be readily extrapolated, it is customary to build a composite curve of the wells in that pool or in a pool where conditions are as analogous as possible. These composite curves are usually constructed on the basis of Lewis and Beal's "Law of Equal Expectation," which states that the wells of any given size in one pool may in the future be expected to produce the same amounts of oil on the average regardless of age. The graphic method devised by them for utilizing this rule is well described in the current "Manual of the Oil and Gas Industry" already referred to, and therefore will not be described here This curve gives results fairly similar to another method sometimes referred to as "Darnell's method" or the "segmental method," which, however, is also based on the "Law of Equal Expectations," and being open to the same criticism, is not here detailed.

*Manual for the Oil and Gas Industry under the Revenue Act of 1918, revised August, 1921. 1921. United States Internal Revenue Office, Washington, D. C.

Time is far too important a factor to be ignored as it is in the Law of Equal Expectations, because the small wells that are used are young edge wells, not old average wells. Appraisal methods, except where the limitation of time does not permit, should, therefore, be based on three variables, one of these being age. The method which recognizes three variables has been called the "Age-Size Method" and was proposed by the author at the meeting of the American Association of Petroleum Geologists in 1921. It consists of plotting the production of the wells of the group in the second year against the production of these same wells for the first year, the third year against the second year, the fourth year against the third year, etc. A smoothed line is drawn through the dots in each of these "scatter diagrams." From these curves, the production for the second year of any intermediate sized well can then be read from the first curve, and with this reading the production for the third year can be read from the second curve, etc. The time consumed in this method is only slightly in excess of the "segmental method" and less than twice that taken for the "family or shingling method." The result justifies it, except where a great deal of appraisal must be done at small expense, as for taxation or where the data are too scanty.

When a well in a new field must be appraised before its records are available, the essential features of the field must be compared with other fields, and the record of the most analogous case must be used.

To obtain the cost of maintenance of the given well, the unit of cost which should be employed is the cost of one well for a year. This is very much more constant than the cost of producing a barrel, since the cost of producing a barrel is relatively slight in a large well and is high in a small well. After knowing the number of wells and the well-day cost and the size of the wells, the barrel-day cost is then worked out separately for each of the successive years

The well-day cost is sometimes taken as a fixture through the several years, or, where the data indicate, a predicted curve of change in its cost may be used.

To assume that the price of oil will remain constant is so surely erroneous that the appraiser should adopt some curve of changing price. This curve will be based on the one hand on the study of the trends of price and of its factors in the past (such as are given in Pogue's "Economics of Petroleum"*), on the current production statistics for their bearing on production in the near future; on the consumption outlook; and, most important of all, on the estimate of petroleum reserves that are available. For this last purpose, the appraiser can use to very good advantage a wide knowledge of the geological conditions of all fields and should follow the current literature of oil-field development with this in mind. The very fact that one's own ideas of future price change from time to time, and that the present price curve shows a high probable error in the past price predictions that were made, by no means indicates that price prediction can be neglected, for past assumptions of flat price have been even more in error. It is certain that the price of oil at the present time is under the influence of the law of diminishing returns, and that it will, on the whole, increase in value and at not a slow rate. Our task is no longer to determine if it will advance but to determine the curve of its advance.

The outlook for the potential competing commodities is well reviewed in a recent book entitled "Gasoline and Other Motor Fuels,"† p. 505-595. It is obvious that the appraiser must keep abreast of all changes in the technology and economics of these potential competitors, as they will determine in large part the upper limits of the oncoming advance in price. It is true that at this time (March 1922) the production of the United States is unprecedentedly large, that oil is being imported from Mexico in great volume and that a condition of over-production now exists. Yet I venture the conclusion that oil must increase in cost, because the Mexican pool now responsible for this large production is a reserve which is being so rapidly depleted that it will be nearly exhausted this summer, and the new pools which are now being developed in the United States and Mexico

*Economics of Petroleum, by Joseph E. Pogue. 1921. Wiley, New York.

†Gasoline and Other Motor Fuels, by Carleton Ellis and Joseph V. Meigs. 1921. Van Nostrand, New York.

are being developed at the cost of more and more extensive wild catting. The chances of success of the new wild cats in both countries are decreasing at a considerable rate. Most of the recent large new pools were not drilled in areas of very high promise and there was considerable chance of failure.

The appraiser nearly always assumes that the technique of producing oil will remain constant; but an examination should be made to ascertain whether the conditions are particularly promising for the utilization of water-drive, pressure restoration by air, or treatment for paraffin; any one of which might change the life and yield of the property. There are, of course, also possible future developments of technique not now foreseen, but it would be best not to add anything to the value for this possibility.

The estimated profits of each future year must be reduced to present value by being multiplied by a compound discount factor. The rate of interest in this compound discount factor may properly vary with the financial and industrial position of the company. For the average company, 10 per cent. is often used, but it is not safe to attempt to standardize this rate at this or any other figure. This rate bears some recognition, of course, of the hazards of the oil business inasmuch as more interest must be paid for money for such investments. However, owing to the hazards of this business, money cannot be raised beyond a fixed percentage of the value at such a rate as this. The remaining part of the money is distinctly speculative and is induced to enter the business with that object in view. Interest rates do not well apply to this portion and an indemnity for the risk must be paid to attract it. Some appraisers combine this discount for risk with a discount factor by making the compound discount higher than one based on 10 per cent., but it is more rational to add a discount for risk instead, as there seems no good reason for compounding the pure risk feature.

So far, only the appraisal of wells has been considered. When we pass to the appraisal of lands not yet drilled it becomes necessary; first, to estimate what a well will cost to complete; second, how large the well will be; and, third, how much

such a well would be worth if successful. But most important of all, and most difficult, is the percentage chance of its being successful. In determining all these questions, and especially the last, all the art and science of the petroleum geologist must be called forth. It is not merely the simple matter of consulting a structural map of the area and of allowing relative values for positions on the structure as shown on the exposed beds, but also the percentage chance of these zones, and therefore it involves, as has been said, the entire resources of the petroleum geologist. It is for this reason that for the appraisal of oil lands one must not only have a training in appraisal but also a geological one of wide application.

One device which is especially urged is that of recording, before the results are known, all the wells that are being drilled in any particular area and classifying them under several heads, such as "inside off-set wells," "outside off-set wells," "wild cat on new structure previously undrilled," "wild cat. structural conditions unknown," etc. The percentage result for each class is then obtained for that district. The important point to bear in mind is that the wells should be classified before the result is known, and all wells placed in one category or another. Trying to produce such statistics by working backward does not give reliable results.

The appraisal of natural-gas properties is much more difficult than that of petroleum properties and the probable error, in spite of the best methods, is probably roughly twice that of petroleum. The first and greatest difficulty lies in the fact that whereas with oil the yield is normally the maximum capacity, in natural gas this is almost never so but is only a fraction of the potential yield, depending upon the ratio between line pressure and well pressure. Whereas the well pressure is regular as to time, the line pressure is decidedly irregular, showing not only a diurnal and a seasonal fluctuation, but also erratic changes due to weather and also to additional gas wells being connected to or disconnected from the line, not to mention the vicissitudes of industrial consumers which may give a series of irregular changes. In postulating the future yield of a natural-gas well,

it is, therefore, necessary to postulate a history as to the sort of "pull" which will be made on the well.

A further difficulty arises in that, whereas the yield of oil is measured, that of gas more frequently than not is unmeasured at least in part. The yield must therefore be determined, calculating the probable yield from the determination of open-flow capacity, minute pressure, or other measurements which do not measure yield but which are merely factors in yield. Ordinarily our best resource is the pressure curve. By determining as well as possible, either directly or by analogy, the amount of gas which has been yielded by the loss of each pound of pressure, the yield can be estimated. Care should be taken not to assume that a pound loss will produce the same amount at different pressure levels of the well. A pound-loss curve should be constructed for as many gas pools as possible in order to have a range of pools from which to pick the most analogous. It is now known that in some pools the pounds lost later in the history of the well yielded more gas and in others less gas. When metering is done, unless it is done right at the well, allowance must be made for leakage, and, even when the gas is metered at the well, errors sometimes arise because of underground leakage.

In conclusion, the hazards of the oil and gas industry are so great that men are prone to be careless and fatalistic, but the amounts at stake are so large that the attitude should, on the contrary, be one of determination to get the closest approximation by all the resources of petroleum geology and statistical and graphical methods, because it is in the better determination of the value of the oil and gas properties that are to be bought, that profitableness in the oil and gas business can be most promoted.

DISCUSSION

MR. H. D. JAMES, *Chairman*:* What are the possibilities in the Hudson Bay district and in Northwestern Canada?

MR. ROSWELL H. JOHNSON: There is an area of some promise adjoining Hudson Bay, to the southwest. There are no wells there, but it can not be considered hopeless as is so much of Central and Eastern Canada. A good area exists in Northwestern Canada; the Fort Norman field comes in there.

MR. H. D. JAMES, *Chairman*: Is that field developed to any extent?

MR. ROSWELL H. JOHNSON: That is a reserve for the distant future.

MR. W. A. WELDIN:† Is it a prediction rather than a matter of present knowledge? Is it on account of the nature of the rock and not on account of any wells drilled there?

MR. ROSWELL H. JOHNSON: There is one well at Fort Norman and a few on Peace River, but economic conditions require higher prices than the present ones.

MR. WINTERS HAYDOCK:‡ Where are the new wells recently reported in Mexico?

MR. ROSWELL H. JOHNSON: On the Isthmus of Tehuantepec.

MR. WINTERS HAYDOCK: Has the petroleum geologist come to any conclusion as to how soon it will be economically profitable to recover oil from oil shale?

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†Blum, Weldin & Co., Pittsburgh.

‡Chief Engineer, Citizens Committee on City Plan of Pittsburgh, Pittsburgh.

MR. ROSWELL H. JOHNSON: In my opinion oil from coal will come before oil from shale. There is no really economically successful oil shale plant in the United States to my knowledge. The Elko, Nev., plant is coming the nearest to it; but my understanding is that it is being nursed and is not an independent economic venture. On the other hand I am informed that the International Coal Products Company, of Clinchfield, Va., is now getting oil from coal, and selling the retorted coal briquetted at a profit. I believe it will be four or five years before oil from shale in large quantities, will be produced. I call attention to the fact that if we want to get anywhere near this tremendous volume of petroluem we are using now we will have to build an enormous number of retorts, and it takes a large retort because of the bulk of the residue. Because of that fact and the amount of capital to make the necessary equipment to cause shale oil to cut in on the petroleum market to any important degree, it would take a long time even after the price has reached the required level.

APPLICATION OF APPRAISAL METHODS FOR RATE MAKING, FEDERAL TAXATION, AND COMMERCIAL PURPOSES

By Paul Ruedemann*

FOR RATE MAKING

Purpose of Appraisals. An enterprise seeks an increase in rates when the earnings resulting from existing rates are inadequate and do not permit a reasonable return on the investment. A natural-gas utility, because its business is to sell a commodity which cannot be reproduced, must explore and expose sufficient quantities of the product to maintain its corporate existence. Increasing labor costs, cost of operation, and investment requirements force the company to guard the safety of the investments by a greater return.

Natural-gas companies are public utilities and as such are required to request changes in rates through a state commission known as a public utilities commission, or public service commission. This body is made up of engineers chosen to examine valuations and pass upon the justness of the claim for rate increase.

Every rate adjustment must comprehend other considerations aside from a return of investment. The components of a rate are many but can be broadly divided into four groups:

1. A reasonable interest on the investment.
2. Covering of current operating expenses, including repairs and replacements not in the nature of capital expenditures.
3. An annuity or amount toward redemption of capital which will eventually return the investment.
4. A return for the intangible values involved in the business such as *going concern, going value, etc.*

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Why Methods Applicable Elsewhere Have Not Been Adopted. In general, the methods used for valuation in other fields are adaptable to rate making. This is primarily true in the case of physical property. However, the gas reserves are not valued on the basis of probable earnings to be derived therefrom but on an arbitrary *acreage basis.*

As with the legal profession, precedent establishes the course of procedure in settling rate claims. The annual analytical method of appraisal as applying to gas reserves, has been developed only in the last four or five years. To the writer's knowledge no attempt has been made to gain recognition of these principles before a public service commission.

A handicap to be expected in attempting to introduce refined appraisal in rate making is the acceptance of a *price scale.* Future earnings depend upon future prices, and such prices can be obtained only through the approval of the commission. However, the gradual change of supply to demand, along with other economic conditions, has in the past necessitated price changes which when arranged in graphical form show a tendency to increase at a nearly exponential rate—exponential rate being a uniform percentage of the preceding year, much on the order of compounding interest. A price change can continue to be anticipated until a certain limit is reached. This limit is not likely to come within the period covered by the life of any wells operated at present.

Advantages and Disadvantages of Present Method. Until such a time as the analytical appraisal methods are applied for rate making in connection with natural-gas properties, the gas reserve value will be an arbitrary amount not related to the resources available or the income to be derived therefrom.

If a standardization of appraisal methods could be effected, the gas company would have data useful for more than one purpose. The present method of arbitrarily fixing acreage values is rapid, and consequently saves expense in the compilation of the report.

Probable Future Recognition of More Refined Principles. As soon as the engineer for the natural-gas company fully

grasps the significance of analytical appraisal it will no doubt be more generally used. It will require manipulation differing slightly from that of oil companies. This is true only for companies acting as producers and marketers. The difference arises due to a wasting asset and a semi-permanent asset. The gas reserves in sight at any one time are limited to the time necessary for recovery. It is not so with transportation and distribution equipment. Much of this equipment is in the nature of permanent investments, complete deterioration being forestalled by repairs and replacements; thus this equipment is in a general uniform condition of usefulness much on the order of a well maintained railroad. In consequence, of the two classes of company assets, a separation becomes essential when applying analytical methods of appraisal. The producing system has a value of gas reserves dependent upon future returns therefrom. The equipment necessary to the operation thereof is a part of this value, and not in addition thereto as it ceases to be of service after the gas is recovered. On the other hand, the value of the equipment of the transportation and distribution system is a part of the valuation fixed on future earnings derived from these systems only to the extent of maintenance costs and depreciation. The value of the equipment is in excess of the value mentioned above. This comes about through its semi-permanent nature.

Application of more scientific methods of appraisal for rate making depends entirely upon the energy and force with which engineers demand recognition thereof.

FOR FEDERAL TAXATION

Difference from Other Appraisals. A valuation of a company's holdings for federal taxation differs from one made for either commercial or rate-making purposes. The differences should be theoretically non-existent, for a property should have but one fixed value. The examining bodies, however, because of precedent or desire to avoid complications, limit the freedom essential to a correct valuation. For rate making the limita-

tions have been mentioned. In the case of federal taxation valuations the primary difference from all others is the price increase and the discount factor.

In natural gas, for the present, an increase in price can be taken only if it is a uniform percentage over a given year. On a graph this would be a straight line. For commercial appraisal the increase might be exponential or on some other type of curve. Thus gas holdings generally get less value for federal taxation than for the purpose of purchase or sale.

For oil holdings a difference also arises in price predictions. Where appraïsal by analytical methods is permissible the price used must be without increase. Here again the value becomes generally less than where predictions are made. There are instances, however, where the value becomes much greater, as for example the use of a price of $6.10 without change in 1921 when a drop was foreseen. This results in a large difference on new wells where most of the production is recovered before the price goes up.

Commercially, there would be more refinement introduced, at least to the extent of justifying the factor by the conditions requiring its use. The differences in discount factors to use are not so great and do not affect the final results so decidedly.

Purposes of Appraisals. There are numerous reasons why valuations are required. Of these reasons, the following might be mentioned:

1. To establish valuations as of March 1, 1913, for depletion deductions.
2. To establish valuations within 30 days of discovery, for depletion deductions.
3. In some cases to set up equipment valuation for the purpose of depreciation.
4. To ascertain whether the cash value of property on Jan. 1, 1914, or the par value of the stock or shares issued therefor, is the lower (This is seldom necessary).
5. To determine invested capital for assets paid in for stock or shares, where a property has been received

as a gift or paid into a corporation for clearly and substantially less than its value.

6. To fix the value of intangible assets for invested capital, if permissible.
7. To find the profit and loss from the sale of capital assets.
8. To establish the value of assets acquired in reorganization, merger, consolidation, or other change of ownership, subject to valuation as provided for in the act.

The last is the least considered, but is one of the most important. Many large corporations have been built up by a process of absorption, through merger or otherwise, of smaller companies. Through failure to recognize this fact the companies not only present their case incorrectly but sacrifice considerable in depletion deductions, etc. The benefit arises mostly through the purpose and application of the valuations. Those made for the discovery date of March 1, 1913, are for the calculation of depletion deductions only. The valuation cannot be taken as invested capital. On the other hand, a valuation made for the purpose of finding the value of assets involved in change of ownership is for invested capital and, consequently, under the law, gets the benefits which accrue to invested capital. These differ from the March 1, 1913, discovery values in that, being invested capital, they can be used in fixing the credits allowable for excess profits; also, depletion and depreciation are permissible as a deduction in 1916 and 1917 on these values. There are several other minor benefits which develop in the tax accounting. Since the transfer comes after March 1, 1913, there are more wells to be valued than at the former date. It therefore devolves upon the company to present full details of the various mergers, etc., to the commission in order to get its case correctly settled.

To offset the benefits derived, there is a tax to be paid on the profit from the sale of capital assets. If the transfer occurred between 1913 and 1917 it is almost negligible, as the tax is less than two per cent., while the excess-profits credits are eight per cent. per annum. Furthermore, the profit is determined

as the difference between the value on March 1, 1913, and the value on the date of transfer. Another loss is that the date of acquisition for determining discovery rights is changed from the date of original acquisition to the date of transfer. This handicap is not as costly as one would suspect when the development of new sands and pools is taken into account. It can safely be stated that a valuation for invested capital is far superior to one for March 1, 1913.

Valuation Methods for March 1, 1913. In localities where many sales have been consummated, the barrel-day method of valuation is preferable for oil properties. Under some circumstances the analytical appraisal may be used.

For gas properties the analytical methods are acceptable at any time, due to the fact that few sales meet the condition of willing seller and willing buyer.

Valuation Methods for Discovery Wells. For oil properties, the barrel-day method is abvisable under certain conditions; especially those found in the Ranger field where transfer prices far exceed the value determinable by application of analytical principles. From these valuations all element of speculation must be removed. As a rule it is impossible to apply any except the analytical methods because few sales of flush production occur.

For gas wells the analytical method is most commonly used. There are few sales, and these seldom at a value commensurate with probable returns. Valuations made by acre yield or other methods must be substantiated and this is possible only by the analytical method.

Unsound Valuations Often Accepted. The fact that the government accepts a valuation is not always a criterion that other valuations can be based on the same principles. Frequently a taxpayer claims much less than his competitors in the same field and the report goes through because of the reasonableness of the claims. At other times a valuation is very poorly made but the results agree with those considered reasonable by the engineers in Washington. This action is necessitated by the desire to achieve standardization in values and unit costs.

An engineer who introduces short cuts which are contrary to the principles of sound analytical appraisal jeopardizes the possibility of acceptance. A report may once pass with the short cuts, not because they are recognized but merely because the claim is reasonable. However, should the claim be larger than is customary the engineers have an immediate basis for rejection in the unsound short cuts. It is therefore advisable to carry out all the steps carefully and conscientiously, and thus eliminate any possible grounds for rejection should the results be higher than usual.

FOR COMMERCIAL APPRAISALS

Method. Only one method of appraisal is recognized as sufficiently accurate to use for commercial purposes and this is the annual analytical method.

Practical Uses. Since federal taxation valuations became a necessity, the way has been paved for the use of greater refinement in commercial appraisals.

The need for valuations occurs many times but is not recognized frequently enough. There are several uses:

1. To determine the value of a property under disposal or purchase.
2. To find out if, under prevailing market conditions, it would be more profitable to operate or to sell.
3. To check the value of assets against the market value of the stock.

In the first case, before closing the deal, the vendor or vendee, or both, should find out the probable net return from the sale of the oil and gas Many of the Osage, Oklahoma, holdings purchased at high bonuses before our entrance into the war never would have paid out had there not been an unprecedented increase in prices. Numerous transfers made at the time of the recent peak of prices resulted in profit to the vendor far above that possible operation of the holdings. Owners who had been making a close study of economic conditions realized this and hastened to dispose of some holdings.

Company officials have failed to appreciate the possibilities of barter as a source of increased returns. An appraisal department should be maintained and operated either as a separate unit or in connection with the geological department. By proper organization it ought to be possible for the engineer in charge to tell on a few hours' notice what the future net return on any property or group of properties is likely to be. This can be done by a comprehensive file of decline curves, price predictions, operating costs, risk factors, etc. With such a file it is also possible to determine quickly the value of surrounding holdings when the amount of production is known. A qualified appraisal engineer should be in charge, for there is too much responsibility involved to leave the task to anyone without the necessary training. Such a department could also handle the sale of leases now being commonly surrendered. There is no reason why a market could not be found and at least the cost recovered on these leases, rather than to charge them off at a loss. One large company operating in the Mid-continent field is handling such sales with success.

Degree of Refinement in Appraisals. Appraisal for commercial purposes offers the highest degree of refinement possible. This is because there is no examining board, such as a public utilities commission or internal revenue bureau, which seeks simplification and standardization. There is no reason why appraisals could not be made so accurately that the results could be tabulated in the books, and annual charges made against the estimates.

Greater refinement is possible in nearly every step of the appraisal but mainly in the price predictions, production estimates, operating costs, and risk factors.

Future of the Petroleum Geologists and Engineers in This Field. Although methods of appraisal have reached a high degree of accuracy, their use has not been fully recognized. The next few years will find rapid progress in the use of appraisals. It is safe to state that many engineers now making appraisals are not qualified to do the work they are attempting. The company officials and technical staff being unaware of the principles

of sound appraisal fail to realize the poor grade of work they are accepting. The fault here lies with those in charge as much as with the appraiser, for they should analyze thoroughly the qualifications of the individual as well as the work.

Because of the geological training essential to appraisal engineering, this class of work comes within the scope of the geologist; consequently, the title of "geologist and appraiser" will soon replace that of geologist.

DISCUSSION

Mr. Maurice R. Scharff:* I want to ask whether my understanding is correct that in the analytical method an estimate is made of the present worth of the difference, in each year, between the value of the product, measured by the price at which it is sold, on the one hand, and its cost, on the other hand, including in cost the operating expenses and the necessary allowances for interest and depreciation on equipment. Is that a correct statement?

Mr. Paul Ruedemann: We do not consider depletion or depreciation. We take merely the full price to be realized each year and the cost of lifting plus a certain share of overhead. Depreciation is not considered, for this reason. The equipment becomes part of the valuation; it is incidental to the getting of the oil from the reservoir, and so it is not considered. Depletion, of course, can not be considered because it is dependent upon the valuation. You get net profit each year by finding the price and taking from it operating cost and a certain share of overhead, and, therefrom, the present net worth of the property.

Mr. Maurice R. Scharff: May I put my previous question in a slightly different form. As I understand it now, in computing the cost of production for the purpose of determining the present worth of the net earnings, depreciation in the equipment is not added, for the reason that the value of the equipment is considered as included in the value of the reserve. The inference is that, if it were desired to separate the value so resulting into the value of equipment and the value of the reserve independent of equipment, and if the value of the equipment could be considered as measured by its cost of reproduction or by some similar method, the value of the reserve would be the difference between the total value found by the analytical method and the value of the equipment; and if the total value found

*Valuation Engineer, Philadelphia Co., Pittsburgh.

by the analytical method did not equal the value of the equipment, as measured by its reproduction cost or otherwise, the conclusion would be that the reserve had no value as such.

Mr. Roswell Johnson:* That is the present inference, yes. You get the valuation and then subtract the physical property. It is difficult to determine what is the value of the reserve and what is the value of the equipment. By taking the present worth without depreciation it is possible to separate equipment value from reserve value after the valuation has been placed.

There has been nothing done with the analytical method with small wells. Frequently the value of the equipment is greater than the present worth of the property, consequently present reserve has no value whatever.

Mr. Maurice R. Scharff: What I have in mind in asking these questions is that in studies that I have made for certain gas companies I have found in several instances that the "analytical method" showed practically no value for gas reserves after making allowance for the value of equipment as measured by its cost of reproduction, less accrued depreciation.

As stated by Mr. Ruedemann, the analytical method has not been presented in detail and with full explanation in any of the gas-rate cases that have come before commissions in our section of the country. Moreover, in Pennsylvania, no rate case of importance has yet been decided, in which the valuation of gas leases was ruled upon by the Public Service Commission. In the one important gas-rate case which has been passed upon by the Commission—that of the Pennsylvania Natural Gas Company—the only values claimed by the Company, and the only value for reserves allowed by the Commission, were on acreage on which the gas rights were owned in fee. The Company excluded from its claim, and the Commission excluded from its valuation, all gas under land held by virtue of leases. Other cases that have been ruled upon by the Commission either have not involved the problem of valuation or else the facts have

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been such that the Commission has been able to dismiss complaints because it was shown that the rates in effect would not yield an excessive return upon any valuation of the property whatever, however low, so that it was not necessary for the Commission to rule upon the value of gas in the ground.

MR. PAUL RUEDEMANN: I might add that I know of one case where they used the analytical method in getting valuation for gas reserves and that was the Greensboro Gas Company. I believe that because of the fact that there was so little contest on the rate case, the Commission overlooked the fact that they used the analytical method. At any rate, the case continued without objection. But one could not call that a fair case since in a more closely contested case there would have been objection before the Commission.

MR. F. A. SIMMONS:* I would like to ask Mr. Ruedemann if the Public Service Commission of Pennsylvania accepted the valuation of the gas holdings of the Greensboro Gas Company, which Mr. Ruedemann made. The newspapers stated that "the valuation was held open by the Commission, in order to provide a later unprejudiced investigation."

MR. MAURICE R. SCHARFF: I think I can explain regarding that. The Commission dismissed the complaint in that case, stating that the evidence showed that the rates in effect would not earn an excessive return even upon the lowest possible physical valuation, without any allowance for value of gas reserves. There was, therefore, no necessity for ruling on the question of valuation at all.

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STANDARDIZATION OF MINE TRACKS

By J. D. Martin*

Perhaps one of the most neglected features entering into the cost of coal production is the one included under the subject generally known as "track" or "haulage".

You can inspect a certain plant and find up-to-the-minute hoisting equipment, tipples, power-plants, machinery, and locomotives—in fact, you may find the greater part of the equipment installed and functioning economically, until you reach the track, switches, and auxiliary apparatus and there you will find that very little progress has been made.

To say that the manufacturers of hoisting, tipple, and power-plant machinery or other modern equipment are more interested in their product, or spend more money for good engineering and hence are fitted to supply better equipment with advances in time, would not be fair to the manufacturers of track equipment; but we do know that some large manufacturers of mine equipment spend enormous amounts of money for research work in order to develop their products, making them more and more efficient and thus saving dollars for the user. The same applies to manufacturers of track equipment to a greater or less extent and the products in themselves are probably as up-to-date as electrical or other apparatus. If the fault does not lie in the materials the only other place it can be is in the application; and there, no doubt, is the seat of a part of the trouble, but not all.

We find at the mines no end of delays due to derailment of motor trips; and derailments mean time lost, which means less tonnage and consequently lower profits. It seems quite incredible that a feature so essential as track work should be so utterly neglected as it generally is. Perhaps less engineering skill is applied to this phase of equipment than to any other, so far as the individual mines are concerned. It is a feature which has been allowed to drift along by itself and to make whatever progress

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it could. The same engineer, superintendent, or manager who is precise in his specifications covering a contract for a structure, hoist, or locomotive may order track work with only a passing thought as to its application; thus the development and progress that have been made, have been in the absence of help received from the mining business in general. We are acquainted with the fact that railroad engineering has been placed on a high plane and very valuable data and theory tabulated for practical use. The result of the investigations of the various engineering societies, together with the experimental products of the manufacturers, has led to a basis of standardization for standard-gage railroad work, and part of the results have found their way into the equipment for light track use. However, the classes of equipment are radically different and the same general designs, the same formulæ, do not generally apply. As has been stated before, there is a lot of research work to be done, experiments to be performed and formulæ to be worked before we are ready to standardize light rail track, and this is work for engineers scientifically trained; the work must be done in a scientific manner if the results are to be as they should.

We must conclude that the subject of standardization of track work, as applied to coal-mines, is a subject covering wide latitudes and, in order that all phases of the subject may receive the proper consideration in their relations to one another, extensive analyses must be made and formulæ developed. The study must include not only the frogs, switch points, switch throws, and the necessary fittings, together with the proper design and application of each, but the widening of the gage on curves; curve resistance and curve compensation, as well as track and train resistance; allowable widening of gage for different weights of rail; the size of wheels and tires for various classes of rolling equipment and track; the gage of trucks with relation to the gage of tracks and the increment or decrement in the truck gage for different wheel-bases, as well as other influences, less important but nevertheless requiring consideration.

In the study of standardization of track work obviously the order of procedure must be systematic, and a general outline

must be made to guide the designs through in some logical order including all modifying factors mentioned. Such an outline would be somewhat as follows:

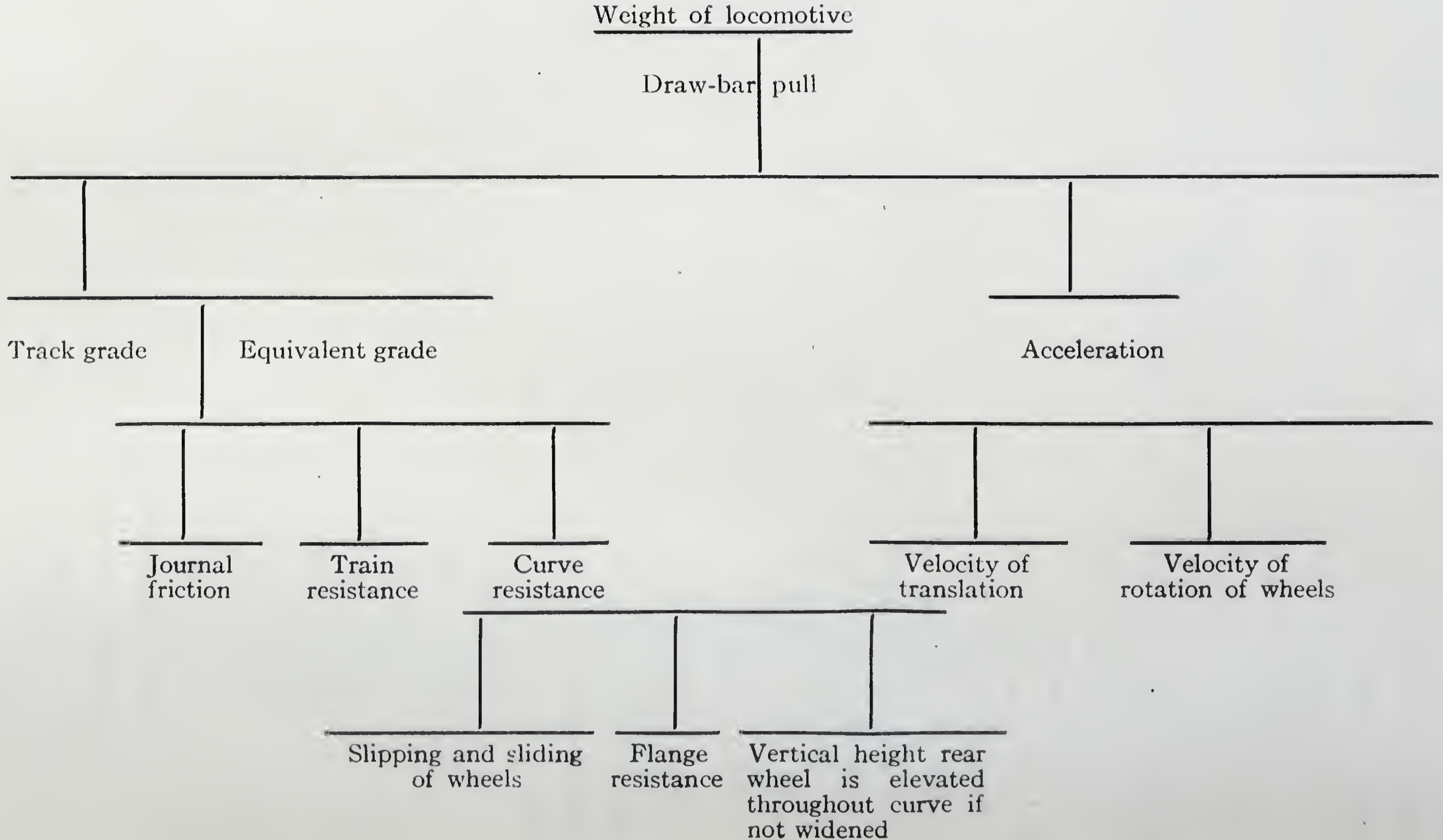
1. Tonnage of plant, or average tonnage over the track.
2. Average and ruling grades.
3. Weight and character of rolling equipment.
4. Class of motor roads or track, whether main-line haulage, semi-main line, butt haulage, or room track.
5. Speed of operation.
6. Road-bed.
7. Costs and economy.

These general classifications taken in sequence will then determine the general designs of track equipment and haulage roads, and at the same time indicate certain relations that must be fulfilled (with the point of economy in view) between the track and the rolling stock. From the general designs the details may then be worked out and adopted for various classes of use.

For example, it is desired to install a motor road to a certain section of an operation, the section itself producing, say, 500 tons of the total tonnage of the mine. Evidently (See Table I) the number and weight of trips per day depend on the size of the locomotive, and its size and weight depend on modifying factors as follows:

1. Grade resistance
2. Equivalent grade resistance due to
   a. journal friction
   b. train resistance
   c. curve resistance
      a. slipping and sliding of wheels on curves
      b. flange resistance
      c. vertical height the rear wheel or wheels are elevated throughout the length of the curve
3. Resistance due to change in velocity
   a. of translation of train
   b. of rotation of wheels

TABLE I. LOCOMOTIVE PERFORMANCE



In order that the locomotive's tractive effort be kept at a minimum all the factors tending to increase it must be kept at a minimum if it is to be operated in the most economical manner. Consider:

1. The grade resistance. This, of course, is determined to a great extent by the local mine conditions which may not permit the necessary grading to reduce the track grade to that desired. We can, however, determine just what per cent. this grade will be.

2. The equivalent per cent. grade due to the factors, journal friction, train resistance and curve resistance.

Journal friction clearly depends upon the type of trucks and bearings used, whether plain or roller bearing.

Train resistance depends upon the condition of the track.

Curve resistance depends upon:

a. The amount of slipping and sliding of the wheels due to the difference in length between the outer and inner rails on the curve, which difference in length must be taken up in the slipping and sliding of wheels and can not be compensated by coning the tires as is sometimes assumed.

b. Flange resistance is due to the bearing of the flange against the outer rail where the super-elevation of the outer rail does not reduce this resistance to zero.

c. Resistance due to the vertical height to which one or two wheels are lifted vertically throughout the length of the curve where the gage of the track is not sufficiently widened.

3. Resistance due to change in velocity. As the train is accelerated from rest to a certain velocity, there is a certain amount of kinetic energy stored in the train due to the velocity of translation of the train itself and to the velocity of rotation of the wheels. When the train is stopped this kinetic energy is not reclaimed but is lost in heat due to friction as the brakes are applied. Thus it becomes evident that the greater the number of times the train is stopped or retarded in its travel from the face to the shaft bottom or other terminal the greater will be the power loss due to this one cause.

After we have adopted the minimum grade which mining

conditions will permit, we may have, say, a maximum or ruling grade of 1.5 per cent. so far as the track grade is concerned. However, if the journal, train, and curve resistances are reduced to their equivalent in per cent. grade, we would find that instead

Radius	Degree of Curve
50'	180°
100'	60°
150'	38°56'
200	28°58'

The combined resistance of the curve due to sliding of wheels and flange resistance may be summarized in the formula deduced by Raymond: The total curve resistanc in pounds per ton total load

$$R_c = A + D\left(\frac{500f\left(G+b+\sqrt{G^2+b^2}\right)}{5730} + .04\right)$$

Where: D = degree of curve
G = track gauge
b = wheel base
f = coefficient of friction

SHORT TABULATION OF CURVE RESISTANCES

Wheel Base	Res. #/Ton (from formula given above)	Total Res. #/Ton Radius 50'	100'	150'	200
2'-0"	0.4+0.20 D	36.4	12.4	8.2	6.2
2'-3"	0.4+0.21 D	38.2	13.0	8.6	6.7
2'-6"	0.4+0.22 D	39.0	13.6	9.0	7.0
2'-9"	0.4+0.225 D	40.9	13.9	9.2	7.2
3'-0"	0.4+0.23 D	41.8	14.2	9.4	7.3

f assumed 1/5

TABULATION SHOWING EQUIVALENT INCREASE IN PER CENT GRADE FOR ABOVE CURVE RESISTANCES

Radius	Equivalent Increase in % Grade for Various Wheel Bases. 24"	27"	30"	33"	36"
50'	1.82	1.91	1.85	2.05	2.14
100'	0.60	0.65	0.68	0.70	0.71
150'	0.41	0.43	0.45	0.46	0.47
200'	0.31	0.31	0.35	0.36	0.37

Fig. 1. Relation of Curve Resistance to Curve Radius.

of operating a train over a ruling grade of 1.5 per cent. we would virtually be operating over as high as two or three per cent. This can be seen from Fig. 1 where curve resistance alone may have an equivalent as high as a two per cent. grade. These conditions and relations are illustrated graphically in Fig. 2.

The power lost due to overcoming the resistance of acceleration may be diminished considerably if motor roads, curves, and

switches are so designed that the train may be accelerated from rest to the desired velocity and maintained at the same velocity from terminal to terminal. If, however, it is necessary to reduce the speed of the train to a very low value for each curve encountered or for each switch passed over, the number of times which the train must be accelerated means power lost in proportion to the number of accelerations.

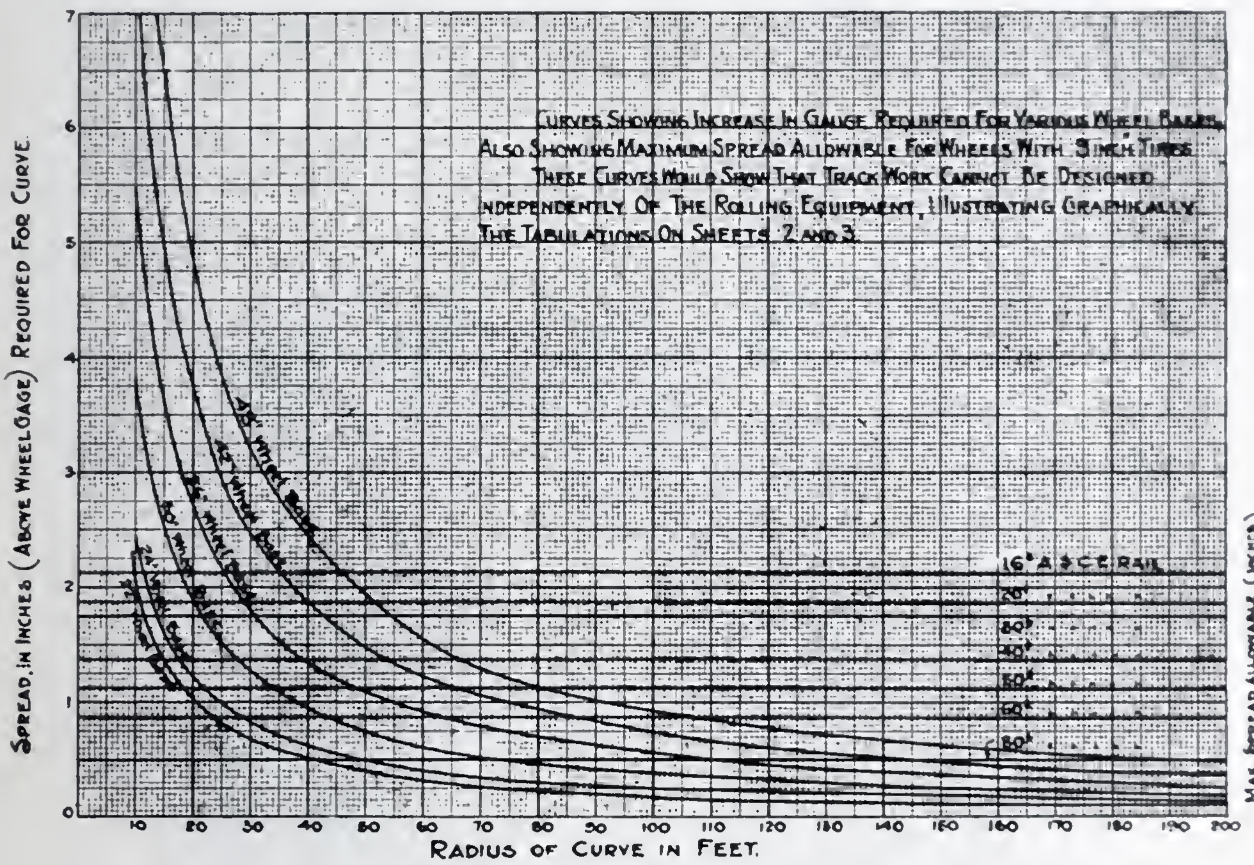
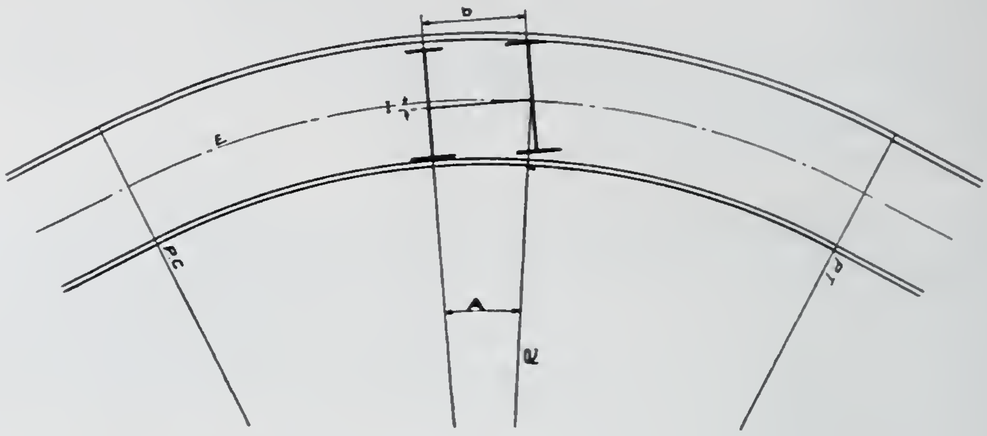


Fig. 2. Graphic Representation of Gage Increase on Curves.

It is clear that these factors all have a large bearing on the total draw-bar pull of the locomotive and consequently on the total power or energy required to move the train from one terminal to another; and it is evident that, if all things are duly considered, the draw-bar pull can be greatly decreased with the proper designs of track work.

In Fig. 1 you have seen that the equivalent per cent. grade due to curve resistance is a big item. In order to reduce this to a minimum the gage of the track on the curves must be properly widened. However, at this point, both the width of tires and the weight of rails must be taken into consideration. If we are to reduce the resistance to a minimum, the gage must be properly widened. See Fig. 3.

We have seen that in order that the resistance due to velocity may be kept at a minimum—and, hence, haulage power bills at a minimum—it is necessary to maintain the train at the same velocity, or as nearly so as possible, from terminal to terminal. To



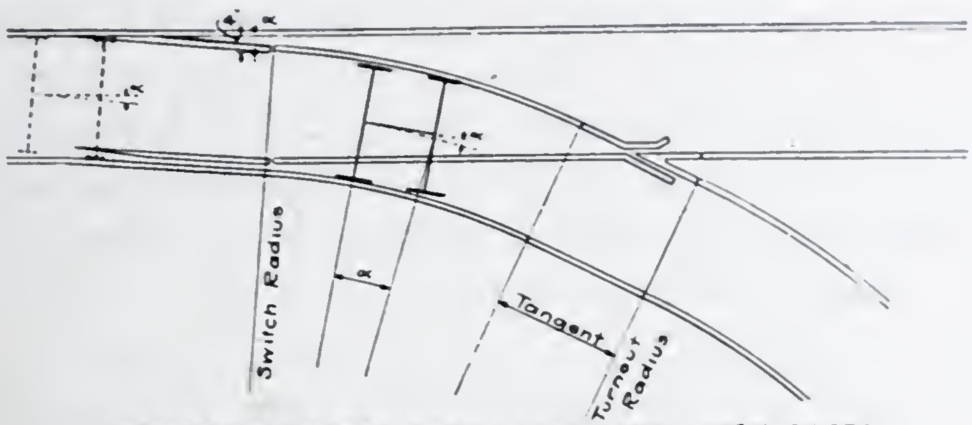
RADIUS	SPREAD OF RAILS (over wheel gauge) FOR A GIVEN WHEEL BASE.									
	24"		30"		36"		42"		48"	
	DEC. OF FT.	INCH	DEC. OF FT.	INCH	DEC. OF FT.	INCH	DEC. OF FT.	INCH	DEC. OF FT.	INCH
10'-0"	.2020	2 7/16								
12'-6"	.1647	2								
15'-0"	1319	1 5/8								
17'-6"	.1146	1 3/8								
20'-0"	.0991	1 3/16	1565	1 7/8						
25'-0"	0801	1	.1253	1 1/2						
30-0"	.0667	13/16	.0981	1 3/16	.1504	1 13/16				
40'-0"	.0500	5/8	.0782	15/16	1129	1 11/32	.1540	1 7/8		
50'-0"	.0399	1/2	.0625	3/4	.0903	1 3/32	1226	1 15/32	1602	1 15/16
75'-0"	0275	5/16	.0417	1/2	.0600	3/4	0813	1	.1069	1 9/32
100-0"	0201	1/4	.0313	3/8	0450	9/16	.0613	3/4	.0800	15/16
125'-0"	.0160	3/16	0250	5/16	0360	7/16	0490	19/32	0640	3/4
150'-0"	.0134	1/8	0208	1/4	0300	3/8	0410	1/2	0526	5/8
175'-0"	.0114	1/8	.0178	7/32	.0257	5/16	.0350	13/32	0451	17/32
200'-0"	.0100	1/8	.0156	3/16	.0220	1/4	.0310	3/8	0392	15/32

NOTE: The above tabulation does not consider the diameter of wheels in the widening required on curves. This factor cannot be eliminated and the above tabulation is therefore subject to correction.

Fig. 3. Increase in Gage Required on Curve for Certain Radii.

accomplish this, the switches over which the train operates, as well as the curves, must be so designed that the train may safely pass over them at its rated velocity. In order that this may be done, certain relations must be properly carried out between the frog, the switch radius and the switch points. An illustration of this is shown in Fig. 4. For example, the angle subtended at

the center of the curve by the wheel-base of the truck remains constant from the point of curvature to the point of tangentcy. In order that the truck shall be drawn around the curve with a uniform draw-bar pull, it may be argued that the angle which the switch rail makes with the straight rail must be maintained equal



TABULATION SHOWING ANGLES α FOR VARIOUS WHEEL BASES

RADIUS	WHEEL BASE 24"	30"	36"	42"	48"
10'-0"	11°-32'-13"	14°-28'-40"	17°-27'-27"	20°-29'-12"	23°-34'-42"
12'-6"	9°-12'-25"	11°-32'-13"	13°-53'-12"	16°-15'-37"	18°-39'-53"
15'-0"	7°-39'-44"	9°-35'-39"	11°-32'-13"	13°-29'-36"	15°-27'-58"
17'-6"	6°-33'-48"	8°-12'-47"	9°-52'-15"	11°-32'-14"	13°-12'-35"
20'-0"	5°-42'-30"	7°-10'-50"	8°-37'-30"	10°-04'-40"	11°-32'-10"
25'-0"	4°-35'-19"	5°-44'-21"	7°-11'-07"	8°-02'-52"	9°-12'-25"
30'-0"	3°-49'-21"	4°-46'-50"	5°-44'-29"	6°-42'-59"	7°-38'-40"
40'-0	2°-51'-58"	3°-35'-00"	4°-18'-05"	5°-01'-11"	5°-44'-21"
50'-0"	2°-17'-33"	2°-51'-58"	3°-26'-23"	4°-00'-50"	4°-35'-19"
75'-0"	1°-31'-41"	1°-54'-37"	2°-17'-33"	2°-40'-29"	3°-03'-06"
100'-0"	1°-08'-46"	1°-25'-57"	1°-43'-09"	2°-00'-21"	2°-17'-33"
125'-0"	0°-55'-00"	1°-08'-46"	1°-22'-31"	1°-36'-16"	1°-50'-02"
150'-0"	0°-45'-50"	0°-57'-18"	1°-08'-46"	1°-20'-13"	1°-31'-41"
175'-0"	0°-39'-18"	0°-49'-07"	0°-58'-56"	1°-08'-46"	1°-18'-35"
200'-0"	0°-34'-23"	0°-42'-59"	0°-51'-34"	1°-00'-10"	1°-08'-46"

ANGLE OF SWITCHRAIL WITH STRAIGHT RAIL

Length of Switch Point	Switch Angle	Length of Switch Point.	Switch Angle
1'-0"	16°-57'-35"	8'-0"	2°-14'-19"
1'-6"	11°-12'-50"	9'-0"	1°-59'-23"
2'-0"	8°-23'-15"	10'-0"	1°-47'-27"
2'-6"	7°-10'-51"	11'-0"	1°-37'-40"
3'-0"	5°-58'-45"	12'-0"	1°-29'-32"
3'-6	5°-07'-21"	13'-0"	1°-22'-39"
4'-0"	4°-28'-50"	14'-0"	1°-16'-44"
4'-6"	3°-58'-55"	15'-0"	1°-11'-37"
5'-0"	3°-35'-00"	16'-0"	1°-07'-09"
5'-6"	3°-15'-26"	17'-0"	0°-58'-00"
6'-0"	2°-59'-08"	18'-0"	0°-55'-43"
6'-6"	2°-45'-20"	19'-0"	0°-51'-49"
7'-0"	2°-33'-30"	20'-0"	0°-50'-09"
7'-6	2°-23'-17"		

¼" at Point 4" Heel Distance

SWITCH RADII & CORRESPONDING SWITCH POINTS

Switch Radius	Length of Switch Points (feet) Wheel Base 24	26"	30"	36"	42"	48"
10'-0"	1'-6	1'-6	1'-6			
12'-6"	2'-0"	2'-0	1'-6"			
15'-0"	2'-6	2'-0	2'-0"	1'-6"		
25'-0"	4'-0"	4'-0	3'-6"	2'-6"	2'-6"	2'-0"
50'-0"	7'-6"	7'-6"	6'-6"	5'-6"	4'-6"	4'-0"
75'-0"	12'-0"	11'-0"	10'-6"	8'-0"	7'-0"	6'-0"
100'-0	15'-6"	15'-0"	13'-0"	11'-0"	9'-0"	7'-6"
150'-0"			17'-0"	16'-0"	14'-0"	12'-0"
200'-0"			20'-0"	19'-0"	17'-6"	16'-0"

Fig. 4. Switch Lengths Required for Curves of Certain Radii.

to the angle subtended at the center of the curve by the truck, thus maintaining a uniform draw-bar pull from the moment the truck is fully on the switch point until it has rounded the curve and is again on straight track. By designing switches with this point in view it is possible that the rolling stock will receive but

one shock, due to impact, when the truck hits the switch rail; whereas, if this angle is not kept constant, each change in it means an additional shock or impact.

All the relations as above set forth may not be theoretically correct to the last analysis but they are sufficiently accurate to indicate that, if the best results are to be obtained, relations between the switch radius, length of switch points, frogs, weight of rail, wheel-base, and width of tires, cannot be chosen arbitrarily but must be chosen through a series of data and tabulations which will accurately guide the designer in the proper choice of the factors entering into the design.

The foregoing theory and method of carrying out these designs is meant only as an illustration of what is required. However, this is a long, complicated, and very much involved subject which requires not only theoretical formulæ and data but also requires considerable empirical data which can be obtained only by making proper dynamometer and other tests on moving trains.

DISCUSSION

MR. W. A. WELDIN, *Chairman*:* This subject deserves careful consideration. As the author has indicated, it is a new subject. There is not much literature to be found upon it, but it is a practical matter that needs attention.

I have observed in a group of mines the economies that are possible through standardization, not only in direct saving by purchasing fewer sizes, but also indirectly by simplification all along the line. That economy feature is the part that interests me most. Some one may be able to give us some information along that line. Mr. Martin has treated at considerable length the mathematical phase of this subject. This treatment ought to be suggestive to those working on the problem and we would like to hear from some of you gentlemen.

MR. C. E. LONG:† The design of the turnouts exhibited on the screen shows the lead rails to be curved from the joint with the switch rail to the joint with the frog.

In this design the joint is jolted in changing the direction of the train coming off the straight switch rail or frog rail. The jolting of the joints has a tendency to kink the rail and loosen the bolts at the joints, thereby increasing the cost of maintenance. This can be overcome, in a measure, by having the ends of the curve a sufficient distance past the joints to permit the front wheels of the cars to pass the joint on straight rail and change the direction two feet, or more, past the joint.

Increasing the length of straight rail will increase the lead. I believe the turnout exhibited should be used only where a short lead is absolutely necessary.

MR. J. D. MARTIN: I think that most frogs used in the mines are too short. This, I believe is the cause of many of the derailments at the point of the frog. The frog should be of sufficient

*Blum, Weldin & Co., Pittsburgh.
†Civil Engineer, Pittsburgh.

length to allow the car truck to be traveling on a tangent at the time the front wheel comes in contact with the frog point.

The Subcommittee on Mine Tracks and Signals, of the American Mining Congress has made certain recommendations for mine track standards, recommending to the coal industry a set of track standards consisting of three different numbered turnouts, using No. 2, 3, and 4 frogs. The Hillman Coal & Coke Company has done a little toward the standardization of track in its mines but we have made very little progress, having standardized only on one or two turnouts so far.

MR. W. A. WELDIN, *Chairman*: Is there any one here from the Bertha Coal Company? I remember that when I was with that company there was quite an advantage in having certain standard fittings and we always had a supply of them on hand. We had a standard room turnout and certain standard heading turnouts. We kept a certain number of them on hand. This was a great convenience, and it eliminated delays in turning rooms and headings because we always had the turnout ready when it was needed.

MR. M. D. GIBSON:* In considering the standardization of mine tracks, we believe the following would be of interest.

The proper size or weight of rail must be determined with due consideration of the nature of the road-bed, the spacing of the ties, the general construction, and the weight of the tonnage to be moved. The recommendations for the different size motors for main haulage, are as follows:

Motor	Rail
6 and 8 ton	30
10	40
15	60

For rooms and all room entries, 20-pound rail should be used.

For 20-pound rails, ties should be three by five inches; for 30- and 40-pound rails, four by six inches; and for 50- and 60-pound rails, five by seven inches.

*Chief Engineer, Bertha Coal Co., Pittsburgh.

All ties should be spaced according to the nature of the bottom, and to give ample support to the traffic. On main haulage 18- to 24-inch centers is the usual practice. In rooms or room entries, this spacing should be made to suit conditions.

One of the chief contributory causes resulting in haulage resistance is poor alignment, due to entries being driven off sights. This adds considerably to maintenance of track and also causes slowing up of the trip, which causes an increase in power consumption. On a poorly aligned track, coal is dropped from the top of the cars, resulting in dirty motor roads and adding to the track resistance. Cost is thereby added to keep haulage, traveling ways and drainage ditches, clean.

All haulage roads should be well ditched and drained to keep road-bed in good condition. A treated tie is recommended on all main haulage.

A responsible person should be in direct charge of all track work and should inspect all spikes, bolts, bonds, frogs, switches, and drainage.

All entries, where turnouts are to be installed, should be driven on sights set by the engineer. We would recommend, for places turned from main haulage, a No. 4 frog, which on a 42-inch gage would be on a curve of 112-foot radius. On tracks other than main haulage, turnouts should be installed, using No. 3 frogs, the radius of which is 63 feet. For rooms, we would suggest a No. 1¾ frog, the radius of which is approximately 17 feet.

In driving room necks a lay-out should be made to suit the frog used and to suit the mining conditions.

In some cases switch stands are not used, the switches being kicked into position and the friction of the bridle holding it in this position. With gathering locomotives a switch stand is desirable.

A standard set of switch ties should be worked out for the different size frogs. A projection of 8 to 15 inches should be allowed on each side of the rail. The larger projection serves to stabilize the track and to keep the tie from splitting when the spikes are driven.

Owing to the low speed in underground haulage, it is not customary to elevate the outer rail of the curve above the inner rail. On short radius curves the usual practice is to allow about one inch increase in track gage.

In regard to gage, we believe 42 inches will suit all conditions. This permits interchanging equipment from one line to another when working the same approximate thickness of vein.

Mr. J. D. Martin: I would like to know what someone else is doing in this line, as I understand several coal companies in this district have made more or less progress along lines of standardization for mine track work.

Mr. C. E. Long: Have you found any occasion for elevating the outer rail on curves?

Mr. J. D. Martin: No, because the speed of the trips is not sufficient to make it necessary to elevate the rails at all.

Mr. W. A. Weldin, *Chairman*: Slowing up with a heavy trip on a main haul is a very wasteful procedure. This is very evident when you are testing the electric current. The surge due to accelerating the trip after slowing down is plainly indicated on the instruments. It may even operate the circuit-breaker. You can often tell just about where the trip is by the circuit-breaker going out.

Mr. W. M. Austin:* I would like to ask if mine switches have ever been constructed similar to street railway switches; that is, with a notch cut in the through rail into which the blunt point of the switch enters when making a turnout. One of the main difficulties with the point switch is the probability of the wheel flange getting between the point and the rail, resulting in derailment. The switch having the notched rail and the blunt point partakes of the desirable characteristics of both the point switch and the stub switch.

*Engineer, Supply Engineering Department, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Mr. W. A. Weldin, *Chairman*: To my knowledge, that is new in mines. Mr. Paul, did you ever run into anything like that in your travels?

Mr. J. W. Paul:* I think I have seen that feature introduced in some mines where a standard-gage track and heavy rail have been used.

Mr. W. A. Weldin, *Chairman*: Generally our rails are too light for that. In street-railway practice, of course, they get into tremendously heavy rails with wide special heads. Another thing they have to watch out for in street traffic is to get a flat top. I used to work for the Pittsburgh Railways Company, and they have some very interesting details in their track work. There may be something we can learn from their practice.

With light rail you would have to reinforce the rail that is notched. That reinforcement could follow very nicely on standardization. If you had but few standards you could have the notched rails shop manufactured.

Mr. C. E. Long: I presume the limit in widening the gage on curves is dependent entirely on the width of wheel tread and rail head.

Mr. J. D. Martin: Possibly so. Of course, the limit to the widening of the gage is small on 20-pound rail which is the predominating weight in coal-mines. I believe the general rule used in widening the gage to determine the maximum width is that the outside edge of the tire shall be even with the outside edge of the rail.

Mr. C. E. Long: In rare instances I have known of more being used in a tight place.

Mr. J. D. Martin: About one-half inch.

Mr. C. E. Long: Yes. The table exhibited for the widening of the gage on curves makes no mention of the various gages in use. You have developed the table for one gage only.

*Chief, Coal Mining Investigations, Pittsburgh Experiment Station, U. S. Bureau of Mines.

Mr. J. D. Martin: Yes. Where it is possible, I believe that any company operating a group of mines should use only one gage.

Mr. W. A. Weldin, *Chairman*: Of course, if possible, you adopt the same gage in all mines of the same company. There has been talk of adopting a standard gage in all mines but they have never gone that far.

Mr. J. D. Martin: Yes, that is one of the things that the Standardization Committee of the American Mining Congress has taken up and they recommended a 42-inch gage for all coal-mines.

Mr. W. A. Weldin, *Chairman*: I know 31 inches is too little. I believe mine-car designers are getting to the point where they will have a good influence toward adopting a standard gage. We used to think the proper design was a car as big as the clearance would permit. I think we are finding out that that is a fallacy, and that the car should be made as low as possible to reduce the labor of loading.

Mr. J. D. Martin: I was doing some work along the same line not long ago and was very much surprised to learn the amount of additional work a man can do by shoveling coal into a car, say 12 inches lower than another car of the same type.

Mr. W. A. Weldin, *Chairman*: They may want a wider gage than 42 inches but I do not think there is any tendency towards a narrower track.

Mr. E. V. Braden:* I believe it is highly in order that we should thank Mr. Martin for his splendid paper. I think this is a new departure in the study of mine tracks. I am sure there has been very little written and it is to be hoped that this excellent start will be the means of getting up interest in this very important matter.

*Engineer, Pittsburgh, Chartiers & Youghiogheny Railway Co., Pittsburgh.

Mr. C. E. Long: In confirmation of this, I wish to state that Mr. Martin has brought together more practical and valuable information on the narrow-gage system, than has up to this time come to my knowledge.

USE OF CEMENT AND CONCRETE IN THE UNDERGROUND WORKINGS OF THE NORTH BUTTE MINING COMPANY

By Robert Linton*

The use of cement in connection with underground operations has increased rapidly within the past few years. The first shaft in the United States to be lined with concrete was at the Tug River coal-mine in West Virginia, in 1903. Since then numerous shafts have been concreted and much concrete used in tunnels and drifts, underground skip pockets, and other workings where permanence is the controlling factor in the selection of construction design.

Cement has also found a wide use underground for fireproofing purposes. Owing to the shifting character of the ground, some shafts cannot be lined with solid concrete. They must be timbered to permit of realignment, but by coating the timbers with cement, which can readily be done with a cement gun, the construction becomes almost as fireproof as solid monolithic construction.

During the past five years cement and concrete have been employed quite extensively in connection with the operations of the North Butte Mining Company, at its mines at Butte, Montana. A description of some of the work done and conclusions reached, in the light of experience to date, are set forth in this paper.

The principal mine of the North Butte Mining Company is operated through three shafts. The main hoisting shaft is the Granite Mountain shaft, 3740 feet deep, equipped with an electric hoist with a capacity of 200 tons per hour from a depth of 4000 feet. The lowest haulage level is the 3600. The Speculator shaft, about 850 feet south of the Granite Mountain, contains auxiliary hoisting equipment—a steam hoist with capacity of 150 tons per hour. This shaft is 3000 feet deep and connected with

*Mining Engineer, New York.

the Granite Mountain on all working levels from the 1600 down. The Gem shaft, 2000 feet deep, is about 1150 feet east of the Granite Mountain and is now used chiefly for ventilation, although equipped with a small hoist which can be put into service in case of emergency. The Speculator and Gem shafts are equipped with reversible Sirocco fans, ordinarily run as exhaust, and serving to control the main air currents. The Granite Mountain shaft is downcast.

There are approximately 36 miles of drifts and cross-cuts in the mine, and over 15 miles of track in service underground. At normal capacity, about 75 stoping faces, 30 drifts and cross-cuts and 20 raises are working; and about 2000 tons of ore are mined per day. Stoping is usually done by the standard square-set method, but the rill or cut-and-fill system is also employed to some extent.

The Butte ores occur in deep-seated fissure veins of steep dip—most commonly from about 60 to 75 degrees from the horizontal. There is profound and complex faulting and extensive alteration of the wall rock in and along the veins. The principal rock is granite, which is cut by numerous instrusions of aplite and quartz porphyry.* For the purposes of this paper, it is only necessary to note that intensive shattering and crushing of the rocks have resulted from the faulting, and that the alteration of the granite in and along the veins is manifested in widespread sericitization and kaolinization. The vein filling is characteristically soft and heavy, and the vein walls frequently tend to break in slabs even where not materially altered and softened by the solutions. The unaltered granite between the veins is hard and dense. The proper location for working shafts is therefore in the foot-wall, although a number of shafts sunk by early operators were located in the hanging-wall, and eventually cross the veins.

Cross-cuts in the hard granite usually require no timbering: drifts and raises, being in the soft, altered vein matter, require timbering throughout, some ground being so heavy that it can be

*For detailed description of the geology of the Butte mines, see: "Ore deposits at Butte, Mont." by Reno H. Sales, Trans. A. I. M. E., v. 46, p. 3.

held only by cribbing. As frequent replacement is necessary, the timbering item is a heavy factor in costs. For the year 1920, the timbering cost (timber and labor) at North Butte was as follows:

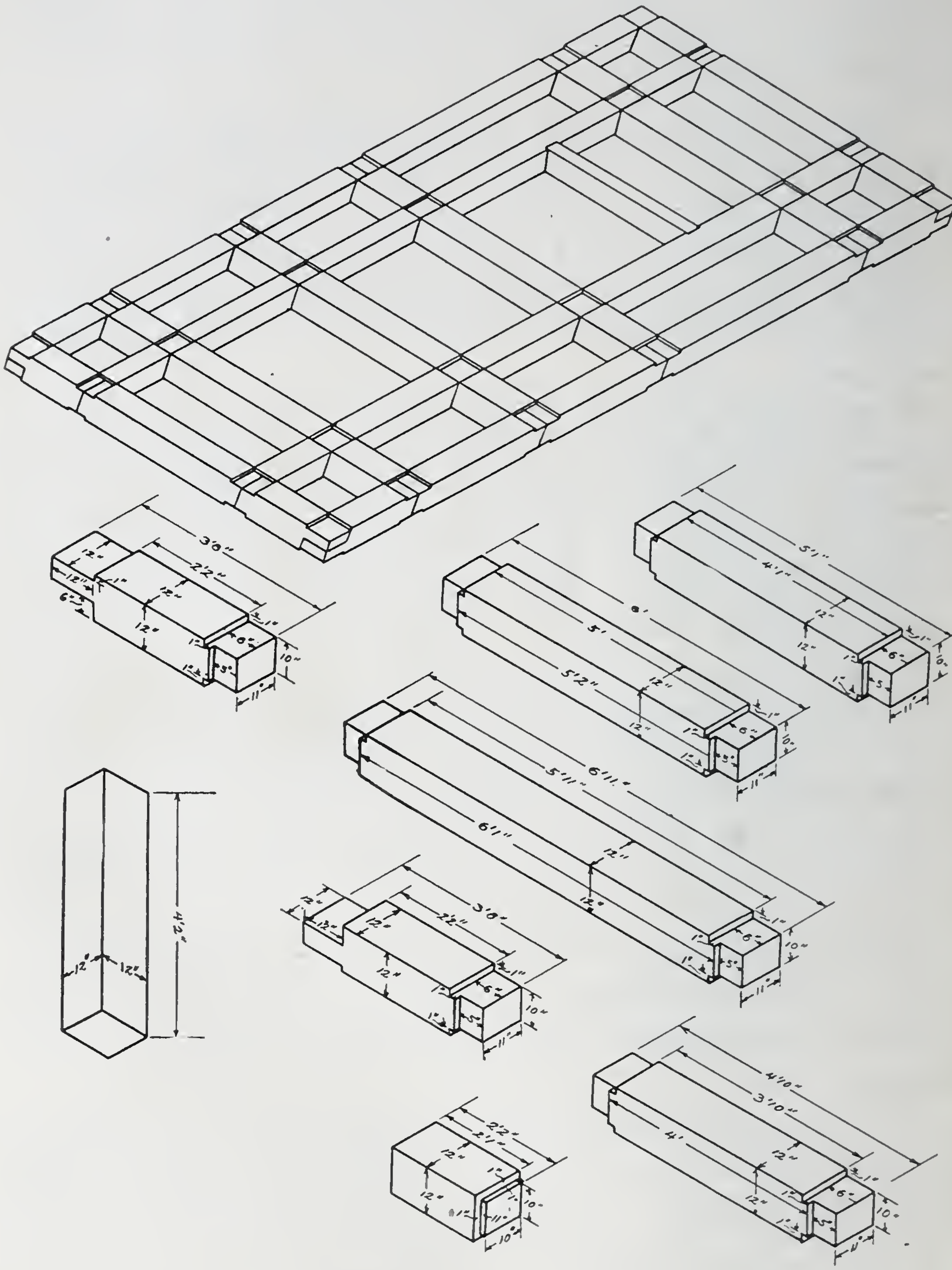


Fig. 1. Detail of Arrangement of Jacket Sets.

Cross-cuts	$1.41 per foot.
Drifts	4.12 per foot.
Raises	16.45 per foot.
Square-set stoping	1.45 per ton.

In some areas there is slow but persistent movement of the entire rock mass, and, where this is the case, or where shafts pass through the soft vein material, the rock movement or pressure gradually throws the shafts out of alignment and they must therefore be plumbed from time to time. To facilitate this, "jacket sets" (false sets bracing the main shaft sets against the surrounding rock) are used (Fig. 1). By lengthening and shortening the blocks about these jacket sets as required, the distorted shaft timbering can again be brought into proper alignment.*

The Speculator shaft was sunk in the year 1897, and is one of the oldest in the north end of the district. It starts in the hanging-wall of the Speculator vein some 75 feet from the outcrop. The vein approaches the shaft until at the 600- and 700-foot levels it lies practically against the shaft timber. From the 700-foot level downward, the dip is reversed and the vein recedes from the shaft quite rapidly. With greater depth the Edith May vein was encountered. The shaft cut into it at about the 2000-foot level and passed entirely out of it into the foot-wall rock at the 2200-foot level. There are, therefore, two sections at which the ground is heavy and difficult to hold—one of about 500 feet where the Speculator vein lies close to the shaft, and the other at the point where the shaft passes through the Edith May vein.

Prior to starting the use of concrete at North Butte, the usual method of employing jacket sets was followed and constant attention was required to keep the shaft in repair and alignment. Ordinarily a crew of 16 men per shift, or 32 men per day, was employed exclusively on this work. It grew increasingly difficult to hold the shaft, owing to the slabbing off of the rock, and required the constant placing of additional jacket sets and readjustment of those already in place.

*For details of timbering in Butte mines see: "Timbering in the Butte mines" by B. H. Dunshee, Trans. A. I. M. E., v. 46, p. 137; "Shaft-sinking methods of Butte" by Norman B. Braly, Trans. A. I. M. E., v. 46, p. 151; "Standardization at North Butte Mining Company" by Robert Linton, Trans. A. I. M. and M. E., v. 66, p. 182.

In 1916, Mr. Braly, General Manager of the North Butte Company, decided to try concrete in this shaft, which was an innovation in the Butte district. The first work done was the construction, at suitable points, of concrete bearers which form permanent supports for the timbering and prevent any further vertical slipping of the timbers resting upon them. They were built about six feet in vertical thickness, the inside coinciding with the inside of the shaft timbers and extending from there outwards to solid rock (Fig. 2). For the concrete the following mix, known as 1-2-4 mixture, was used:

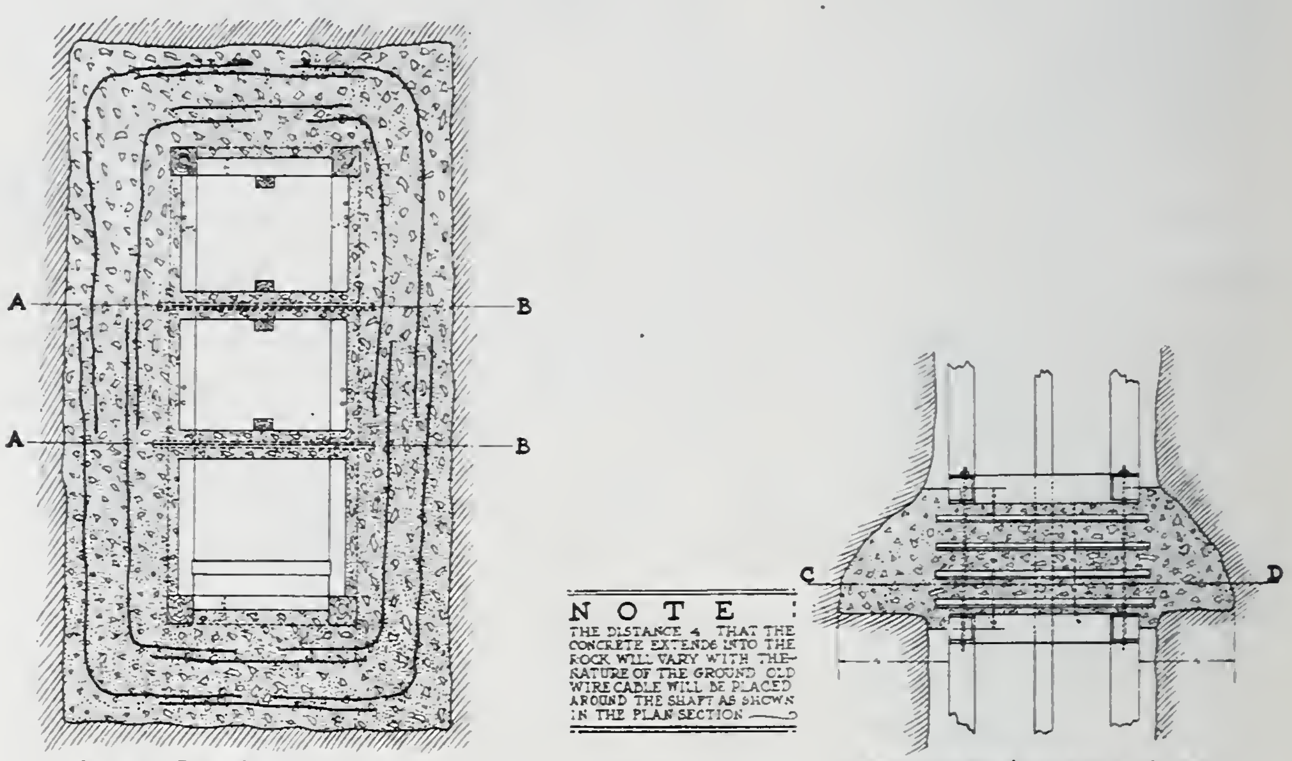


Fig. 2. Reinforced Concrete Support for Speculator Shaft.

Cement	1	part by volume.
Sand	2	parts by volume.
Gravel	4	parts by volume.

The concrete was reinforced with discarded hoisting cables (1.25 inches in diameter) and with old steel rails.

The use of these bearers proved so satisfactory that it was decided to extend the concreting through all of the heavy ground. Bearers were placed at convenient points and, between them walls were built up 15 inches thick and backfilled with crushed rock. This work totaled about 500 linear feet.

The resultant economy is apparent by comparing the cost in 1916 with that of the last six months of 1920. In 1916, there were employed on Speculator shaft repairs an average of about 32 men with a total cost for the year of $53,200. Recalculating this on the basis of wages in effect in 1920, the cost would be increased to an average of $5833 per month. During the six months ended Dec. 31, 1920, the average force was 2.4 shifts per day, and the total monthly cost of repairs to the Speculator shaft averaged only $389.75.

About the same time, studies were initiated by the management to investigate the use of cement in the lateral workings with a view to determining what saving in cost of timbering maintenance could be effected, especially in timbered drifts. These investigations followed four lines:

1. Use of solid concrete slabs of practically the same dimensions, and placed underground in exactly the same manner, as the timbered sets.

2. Coating the timbered sets with cement, either before setting up or immediately after.

3. Coating with cement, timbers which had been in place for some time, and in which decay had begun to develop but not sufficiently to weaken them seriously.

4. Coating with cement, ground which tends to slab when exposed to the air, with a view to determining whether the sealing of such ground and keeping it away from atmospheric influences would prevent slabbing.

These investigations covered a considerable length of time, and the conclusions reached are as follows:

1. Concrete members can be made having the requisite strength, but, owing to high cost and excessive weight, their use is not justified.

2. Coating new timbers with cement materially lengthens their life, especially in hot and humid workings. In very heavy ground, however, the timbers are eventually crushed or split and must be replaced, so that practically no economy results from coating them in such cases.

3. Coating old timbers with cement does arrest decay when not too advanced, and undoubtedly prolongs the life of timbers so coated.

4. Cement coating of ground which tends to air slack and slab, forms an effective air seal and, if the cement is applied immediately after the ground is broken and the rock face exposed, there is practically no danger of rock falls occurring.

Naturally the most positive form of construction would be to line the workings entirely with concrete, as in railroad tunnels, but, except at shaft stations and for haulage ways which remain in operation for many years, the high cost of doing this is not war-

Fig. 3. Cement Gun in Operation.

ranted. No such work (aside from stations) has been done at North Butte.

The cement gun (Fig. 3) is used for coating the timbers and exposed wooden surfaces. This apparatus, which is extremely

convenient and effective for underground work, sprays the grout by compressed air over the surface to be coated. The materials—cement and sand—are mixed dry and poured into a hopper communicating with the upper chamber of the machine. The mixture is fed intermittently to the lower chamber and is forced out—still dry—through the hose and into the nozzle. Here water is added through needle jets under higher pressure than the air and the wet material driven with considerable force against the timbers, forming a very hard and dense mortar. The name gunite has been given to this product and is in general use.*

Cement does not adhere well to wood in most cases; consequently, before the timbers are coated, expanded metal or woven wire (not coarser than one-inch mesh) is tacked to them. This acts as a light reinforcement throughout the entire film of cement, which averages about ⅜ of an inch thick, and insures its permanent adhesion to the structure.

The cement gun can also be used very effectively for fireproofing surface buildings. A rough board structure covered with woven wire and coated with cement is entirely fireproof and at the same time presents a very neat and attractive appearance.

In 1917, a fire in the Granite Mountain shaft, resulting from the accidental ignition of an insulated power cable while it was being installed, destroyed the timbering from the 1700- to the 2800-foot level. The shaft was badly caved for considerable portions of the distance, as were several of the stations as well. This caved condition rendered the problem of repairs extremely serious. It was obviously impossible to retimber certain sections, so it was necessary to devise some other means of making repairs, or sink a new shaft, an alternative not only extremely costly but involving long delay. The experience with concrete in the Speculator shaft naturally suggested its use for this job, and it was therefore decided to make the repairs by using monolithic concrete for the entire length of shaft in which the timbers had been destroyed. The concreting was eventually extended to below the 3000-foot level. As above stated, the Granite Mountain shaft

*"Construction work by cement gun methods," by Arthur J. White. Proceedings, Engineers' Society of Western Pennsylvania, v. 36, p. 109.

was connected with the Speculator shaft on all levels comprised within the portion of the shaft destroyed, which made it possible to prosecute the work on each level simultaneously, starting at each sill, after carefully bulkheading the shaft above, and carrying the work down to the next level, about 200 feet below.

Very close engineering was of course required, since after completion of the work there would be no possibility of realigning the shaft if any section should prove to be out of position. Therefore, the first work done was to have complete resurveys made by two independent crews checking against each other and against the survey points previously located underground. No concreting was done until these surveys were brought into practical agreement, and, as the work progressed, the engineers kept close control of alignment. As a result, the connections were all close and the finished shaft as straight as if it had been concreted continuously instead of in sections.

Prior to working out the details of the structure and methods to be used, Mr. Braly, through the courtesy of the Calumet and Arizona Mining Company, and Inspiration Consolidated Copper Company, was afforded the opportunity of visiting the concreted shafts at their mines in Arizona and obtained some very useful suggestions bearing on the work in hand. The Foundation Company of New York was also called into consultation to secure the benefit of that company's wide and successful experience in sinking and concreting shafts through quicksand and other difficult formations. The information thus obtained was used in connection with the experience gained in concreting the Speculator shaft, and plans for the repairs were developed which were successfully carried out.

Owing to the caved condition of so much of the shaft it was essential to design a structure which would possess sufficient strength and rigidity to resist any lateral pressure to which it might be subjected. These requirements were met by building reinforced concrete around a structural steel framework. Six-inch, 12½-pound beams were used for the horizontal members and 10-inch, 25-pound beams for the vertical members, connections being ⅜-inch angles and splice-bars riveted to the beams with

⅝-inch rivets. The relation of the framework to the concreting and shaft timbering is shown in Fig. 4, and details of the structure appear in Fig. 5 and 6.

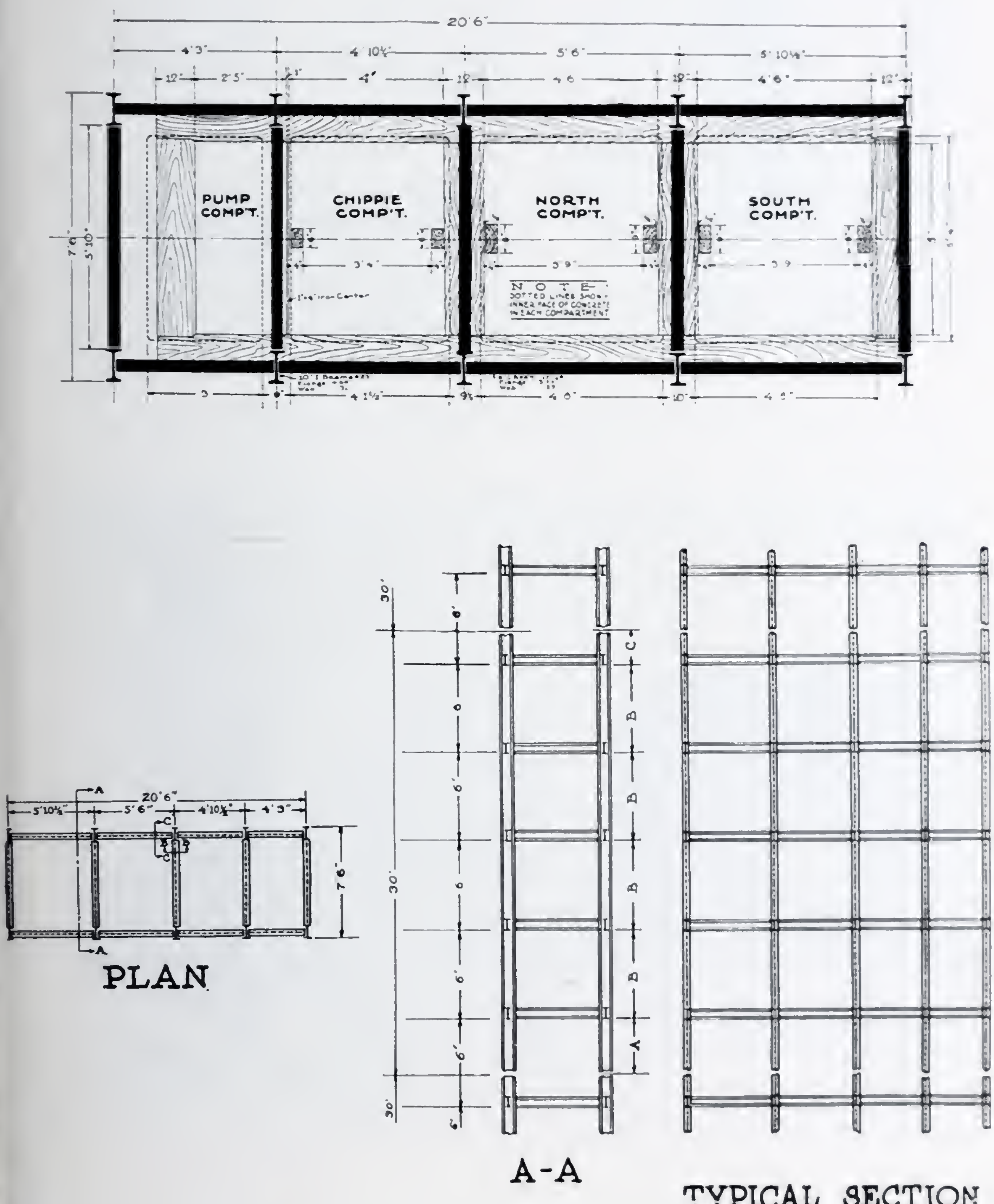
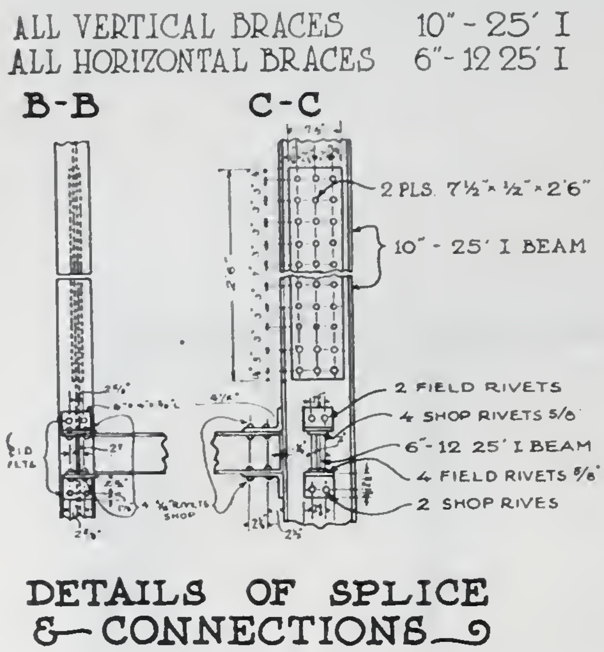


Fig. 4. Plan of Granite Mountain Shaft.



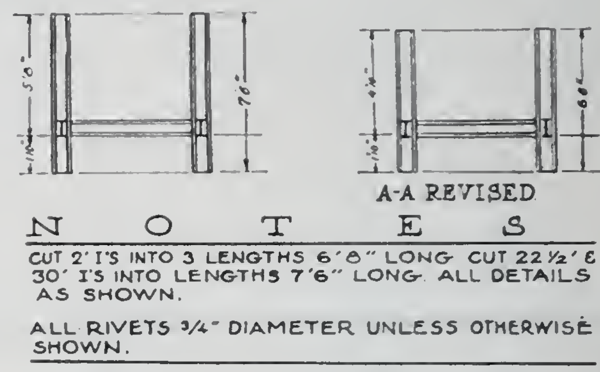


TABLE OF STRUT SPACING

BRACE LENGTHS	20'	22½'	25'	27½'	30'	32½'
A	4'4"	3'3½"	3'11"	3'2"	3'8"	4'2"
B	6'8"	5'7½"	6'3"	5'6"	6'	6'6"
Nº OF STRUTS	3	4	4	5	5	5
C	2'4"	2'4"	2'4"	2'4"	2'4"	2'4"

NOTE: AT LEAST 20 BRACES OF EQUAL LENGTH REQUIRED.

Fig. 5. Structural Steel for Concrete Lining of Granite Mountain Shaft.

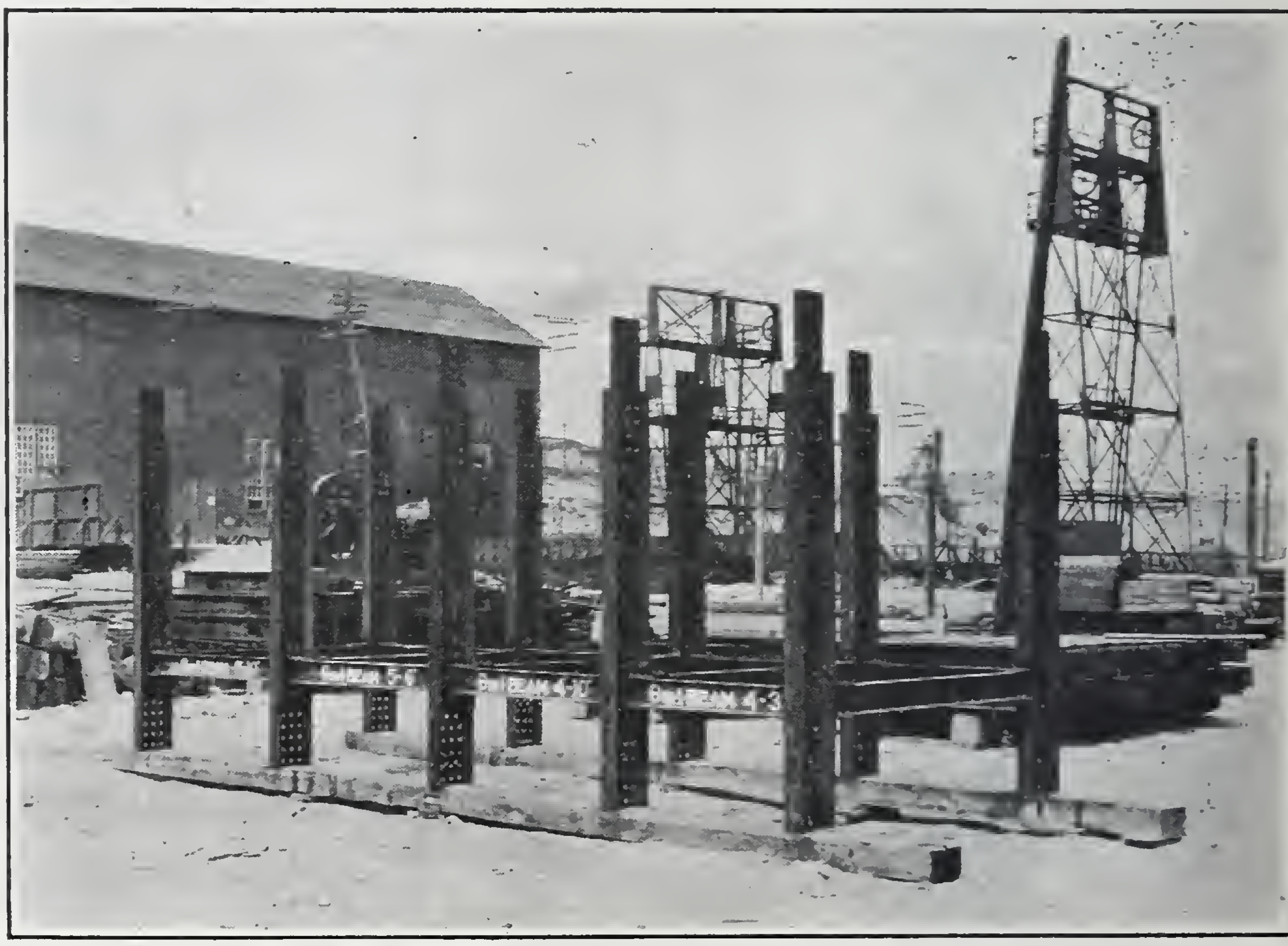


Fig. 6. Structural Steel Used at Granite Mountain Shaft.

The steel structure is carried on solid reinforced concrete bearers placed at carefully selected points in the shaft where the

ground is firm. The steel framework is embedded in these bearers, which carry the weight of the entire structure. Between bearers the concrete shaft lining varies in thickness from 15 to 20 inches according to the character of the ground. The four compartments of the shaft are separated from each other by solid partitions, 10 inches thick between the main hoisting compartments; 9½ inches thick between the north hoisting compartment and the "Chippie", or man-hoist compartment; and 9 inches thick between the man-hoist and pipe and cable compartments. For a few short stretches these partitions were extended to form ribs bracing the structures against the solid rock. The entire space between the concrete walls and the rock behind was of course entirely filled with loose rock; but, where the space was four inches or less, no back forms were used and the concrete extended out to the solid rock.

The first step in the work on each level was to clear connecting haulage ways of fallen rock and debris, repair the stations, and put them in shape to push the work in the shaft. The caved ground around the shaft proper was then secured by driving overhead and side spiling, and the shaft cleared of debris on the station level. Structural steel sets were then placed in the shaft—using the greatest care to locate them accurately, according to the survey—and the "back" bulkheaded for the safety of the shaft crew.

Sinking through the caved rock and debris was then begun and structural steel sets placed as fast as there was room to hang them. Much of the ground required spiling, which was driven from 6- by 10-inch timbers resting against the steel (Fig. 7). In the heavier ground the steel sets were braced with timbers which were removed as the concrete was poured.

A bearer was placed when a suitable point was reached, and, as soon as the concrete was thoroughly set, excavating and placing steel was resumed and continued until another bearer was placed or the next level below was reached. Commencing from the bottom and proceeding upward, forms were then placed and the concrete poured. The concrete was mixed on the level above and handled through six-inch pipes to the point of use. The maximum distance that the mixed concrete was spouted was 400 feet.

The standard 1-2-4 mix was used throughout. Crushed reverberatory slag from the Anaconda smelter was used interchangeably with the limestone, and with results equally satisfactory. Analyses of the materials are as follows:

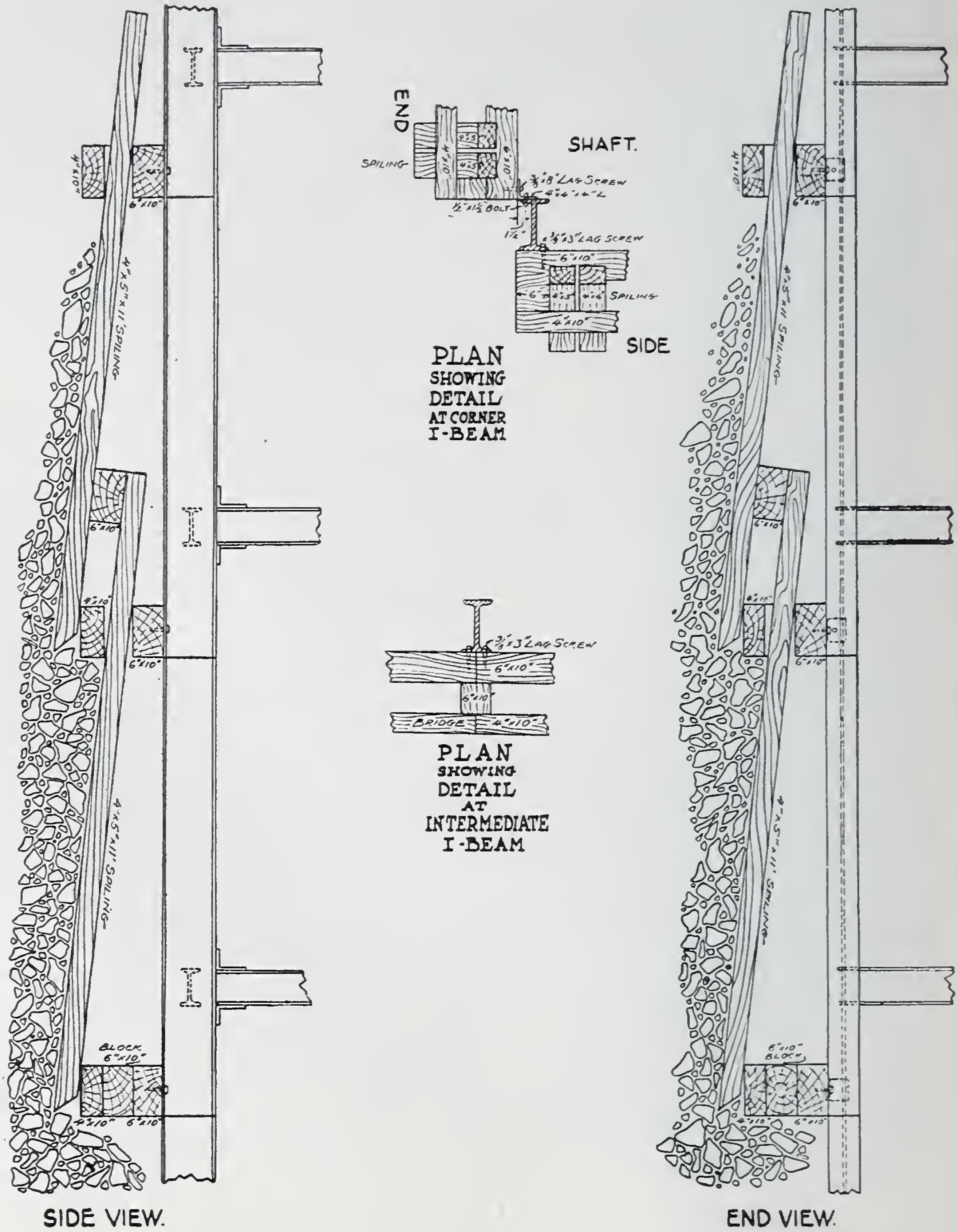


Fig. 7. Detail of Spiling Through Caved Ground.

	Limestone per cent.	Reverberatory slag per cent.
SiO_2	7.8	39.5
FeO	1.4	41.0
Al_2O_3	0.4	7.8
CaO	49.8	6.1
CO_2	39.2	——
S	——	0.5

Both steel and wooden forms were used, but for this particular work the wooden forms proved to be much more satisfactory. They were cheaper, lighter, and easier to handle, and the concrete did not adhere to the wood as much as to the steel. While the concreting was being done, as the forms were removed from a finished section they were hoisted with ropes through other forms above holding freshly poured concrete, and reset for use again. The space through which the forms were hoisted was cramped, and therefore the lighter the forms the more easily they could be handled, and the less danger there was to men working below. Where a new shaft is being sunk and concreted at the same time, steel forms are usually preferable to wooden ones, since the working conditions are very different from the conditions under which the Granite Mountain repairs were made. Details of the steel forms used are shown in Fig. 8 and 9.

As the shaft was clear above the 1800-foot level, materials for concreting down to the 2000 level were handled through the Granite Mountain shaft. On all other levels the materials were lowered through the Speculator shaft and trammed to the Granite Mountain. Work was carried forward simultaneously on the 1800, 2000, 2200, 2400, 2600, 2800, and 3000 levels

The most difficult situation was on the 2000 level. Here the station was entirely caved to a height of over 50 feet above the sill, and the cross-cuts leading from it were caved for a total combined distance of 150 feet. Furthermore, the shaft walls were caved for some distance back—just how far is not known, as no attempt was made to reach solid rock at the station level. To reach the shaft, a timbered raise was run through the broken rock to the solid rock 50 feet above the sill, and a passageway

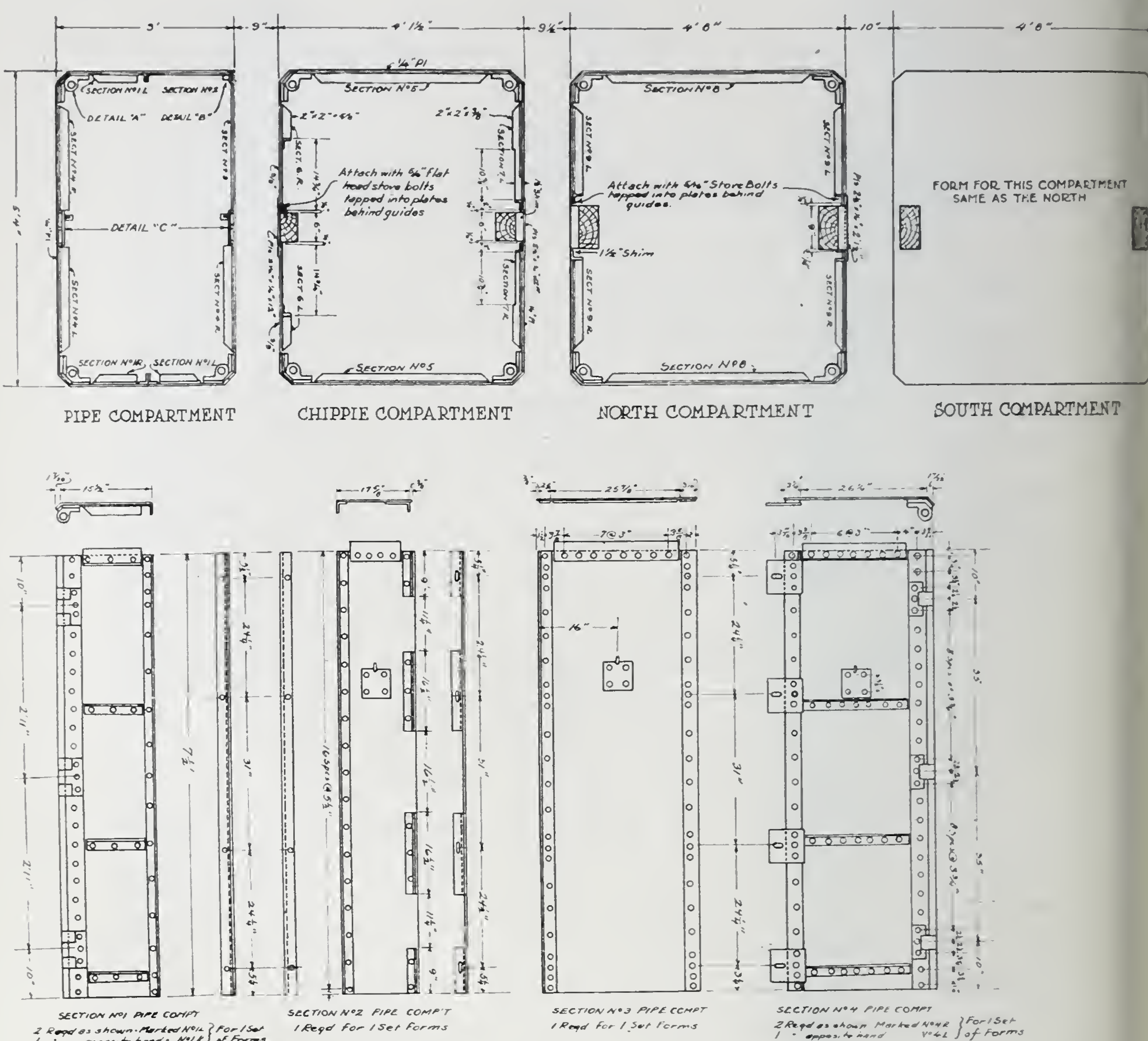


Fig. 8. Detail of Steel Forms for Concrete Work in Granite Mountain Shaft.

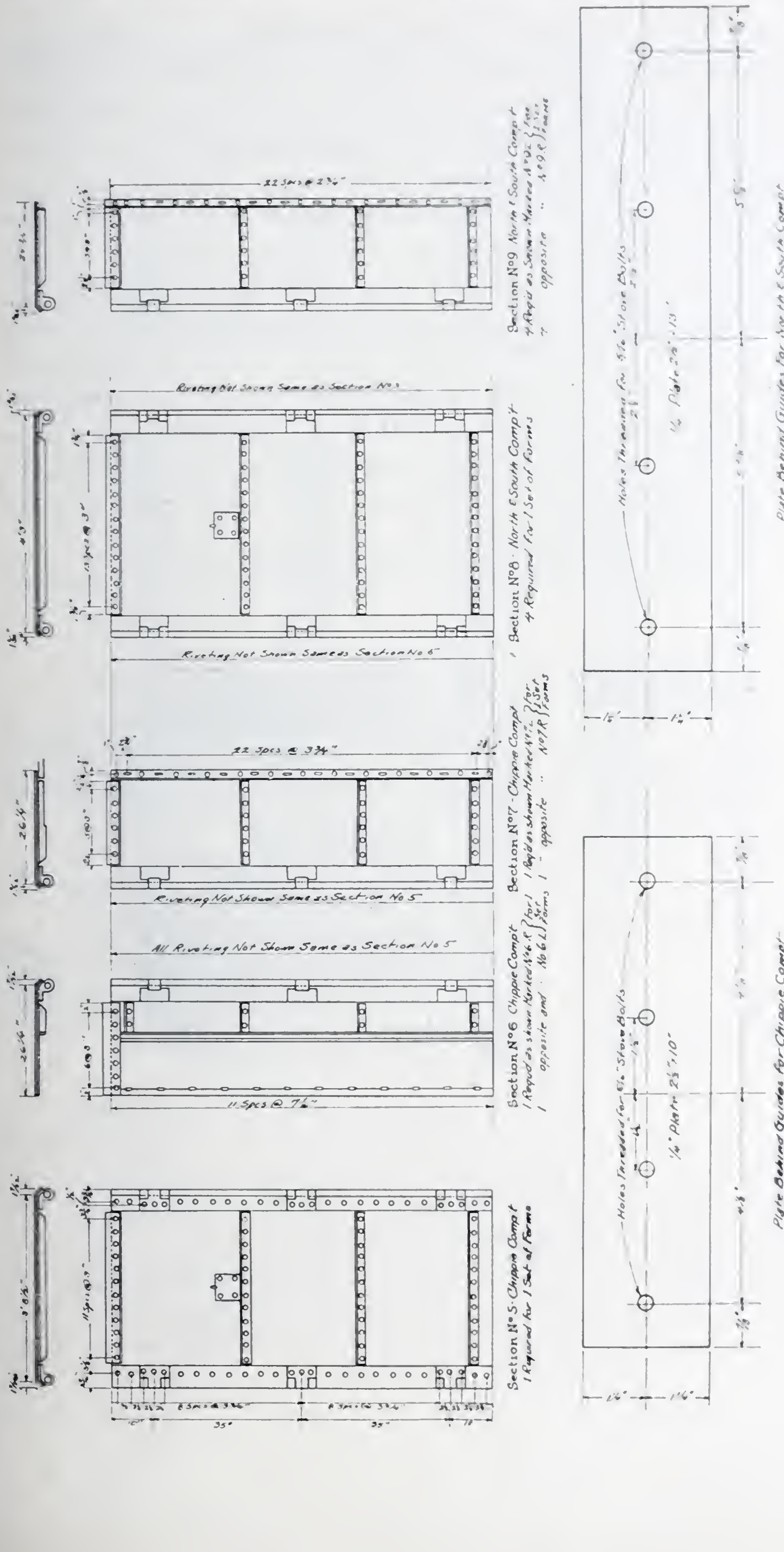


Fig. 9. Detail of Steel Forms for Concrete Work in Granite Mountain Shaft.

was timbered to the shaft. To support this heavy ground, bridge trusses of timber were built as shown in Fig 10. In this way the heavy ground above was secured and a safe and permanent passageway provided through which approach to the shaft could be made. The lateral pressure in the shaft at this point was also very heavy—so great that two 24-inch steel beams which were placed to brace the spiling at the ends of the shaft were badly buckled. By slow and careful work the ground was finally spiled, and the steel placed to a point 66 feet below the level where the rock was sufficiently firm to hold a bearer. The shaft here was concreted as in other cases, except that the walls were made 20 inches thick and very heavily reinforced. The reinforcing bars used in this section were ⅞-inch, cold-twisted, square bars spaced eight inches apart between horizontal pieces and 16 inches apart for the vertical members.

Standard inserts for guide bolts, shown in Fig. 11, were em-

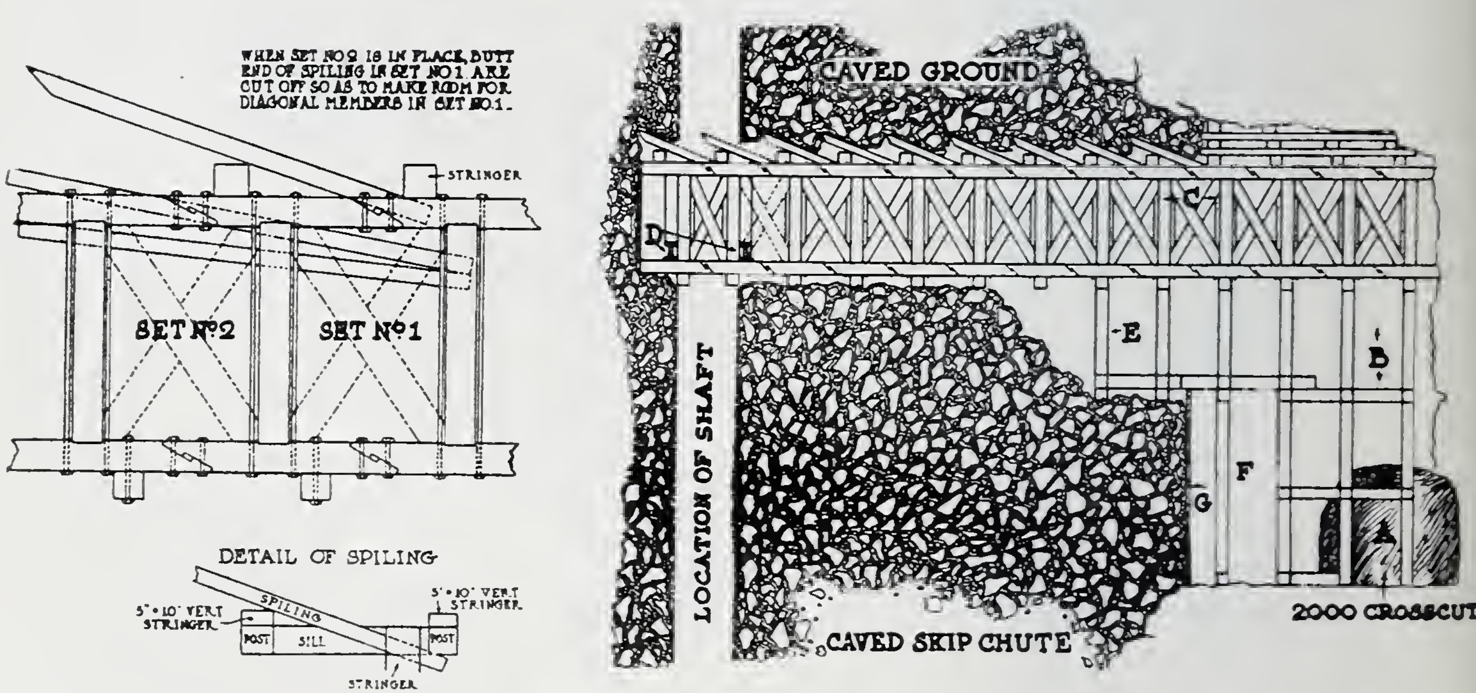


Fig. 10. Detail of Truss.

bedded in the concrete in pairs five feet apart. They furnish amply strong supports for the guides and at the same time permit easy removal and replacement of broken bolts.

The shaft was concreted from a point 90 feet above the 1800 station to 50 feet below the 3000, or a total distance of 1340 feet. The structural steel was carried down to 100 feet below the 2400

level. Below that point the shaft was not so badly caved, although filled with rock and debris, and reinforced concrete alone

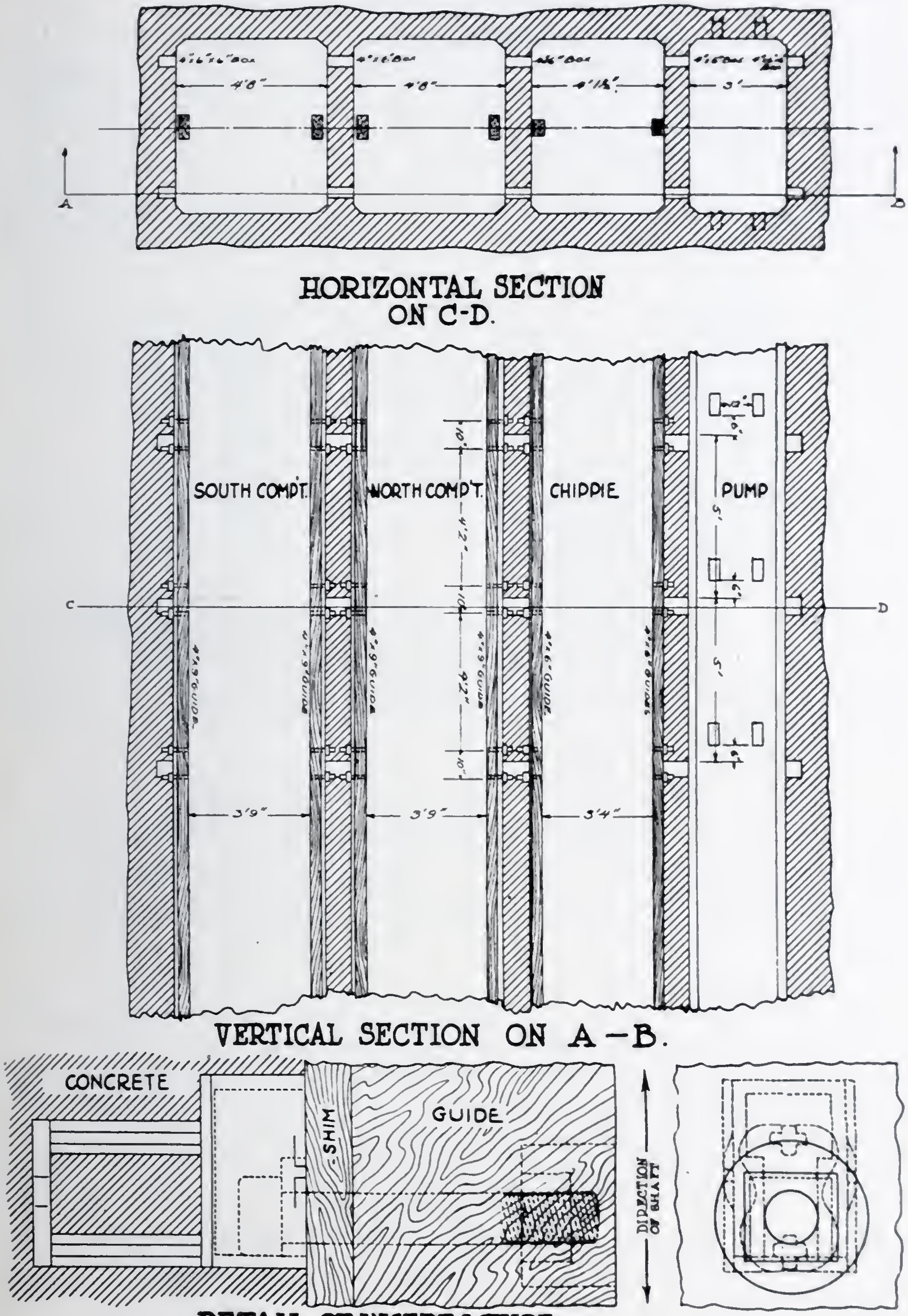


Fig. 11. Detail of Granite Mountain Shaft.

was used. Of the total of 1340 feet, a distance of 813 feet was repaired by using concrete with steel framework, and 527 feet without the structural steel.

The 2000 station was concreted for a length of 50 feet; the 1800, 12 feet; the 2200, 16 feet; the 2400, five feet; the 2600, 12 feet; and the 2800, six feet. Skip pockets on all the above mentioned stations were concreted.

There was placed altogether a total of 6380 cubic yards of concrete. The total materials used were as follows:

Cement	38280	sacks
Sand	3190	yards
Crushed rock	1075	yards
Slag	4655	yards
Reinforcing bars	376	tons
Six-inch steel beams	7700	feet
Ten-inch steel beams	8130	feet

There were used, on an average, 118 pounds of reinforcing steel per cubic yard of concrete set. In the shaft proper, including bearers, there was used an average of 390 pounds per linear foot.

In doing the preparatory work 14,163 tons of rock (cleaned out of the caved stations and shaft) were hoisted; in addition to timber, pipe, and other debris. For spiling, and temporary timbering, 989,424 feet (board measure) of timber and lumber were used.

The repairs were commenced on Aug. 30, and the first concrete was poured on Sept. 12; the concreting was finished on Jan. 20 of the following year, and the first ore was hoisted through the repaired shaft on Feb. 1. The entire job was done in 22 weeks—a remarkable record considering the difficulties encountered. The cost was necessarily high since speed was the most essential factor. Cost of concreting (mucking not included) for two sections of the shaft—one where steel construction was used.

and the other concrete without steel construction—are given below:

Cost of concreting

With steel framework

15 days' work 82½ feet concreted	Cost per foot of shaft Labor	 Material	 Total
Back forms	$ 9.65	$ 1.34	$10.99
Reinforcing	6.55	10.90	17.45
Stripping and setting forms	20.50		20.55
Concreting	17.60		17.60
Handling material	9.15		9.15
Cement		13.35	13.35
Sand		2.26	2.26
Slag		4.90	4.90
Structural steel		31.40	31.40
Placing structural steel	4.80		4.80
Total	$68.25	$64.15	$132.40

Without steel framework

30 days' work 75 feet concreted	Cost per foot of shaft Labor	 Material	 Total
Forms	$ 3.40	$ .25	$ 3.65
Reinforcing	5.20	14.10	19.30
Stripping and setting forms	16.70		16.70
Concreting	7.95		7.95
Handling material	9.15		9.15
Cement		11.50	11.50
Sand		1.60	1.60
Slag		3.45	3.45
Total	$42.40	$ 30.90	$73.30

Between the top of the monolithic construction and the collar of the shaft, the compartment containing the manway with sub-compartment carrying the pipe lines and electric cables was fire-proofed with gunite. This work was done after the shaft was put into commission and was completed without interfering with hoisting.

The concrete has now been in place for nearly three years. During that time no repairs whatsoever have been required, the concrete has developed no cracks and is in as good condition as when placed. There seems to be no doubt that it will so remain as long as the shaft remains in service.

In the period of approximately five years during which concrete has been in use at the North Butte mines excellent opportunity has been afforded to study its advantages and the economies resulting from substituting this type of construction

for timber. The following conclusions may be drawn from this experience:

1. Where a shaft is to be used over a period of years there is decided economy in concreting it, and the work should be done while the shaft is being sunk. There is some addition to first cost, but this is more than compensated for by the saving in repairs.

2. Similarily it is economy to concrete an existing timbered shaft if it is demonstrated that the life of the mine will be prolonged over a sufficient period of years to warrant the expenditure.

3. The length of life of a mine necessary to justify concreting varies with the conditions above noted, but it is believed that with few exceptions there would be a saving if the shaft is to be used for a period of 10 years.

4. The above economies do not take into account the advantages resulting from having the shaft absolutely fireproof and entirely obviating the risk of fire, always existing in timbered shafts, if dry.

5. The use of concrete at shaft stations is desirable chiefly on account of greater protection against fire, but this can be achieved as well by coating the timbers of the station with gunite.

6. Solid concrete construction in haulage ways is justified only where the ground is heavy and a large tonnage is to be transported over a considerable period of years; likewise, the advantage of using concrete slabs instead of timbers is not justified by the advantages obtained.

7. In hot and humid workings, especially if there is only moderate ground presssure, there is a decided economy in coating timbers with gunite when installed, since the life of the timbers is very materially lengthened.

DISCUSSION

Mr. H. N. Eavenson :* Does increased amount of footage obtained in the use of standard drill rounds require more powder?

Mr. Robert Linton : Slightly more powder is required but much less than would be in proportion to the additional rock broken.

Mr. Graham Bright :† Have you found any advantage in the use of treated rather than untreated timbers?

Mr. Arthur J. White :‡ I would like to ask you about the use of gunite on rock faces; whether there is any spalling; and what the approximate temperature was when the gunite was applied; also whether gunite was used in covering structural steel supports.

Mr. Robert Linton : The gunite was applied directly to the rock faces and there was no spalling after it was applied. We did not of course apply the cement until after the rock face had cooled so that the gunite was applied at the ordinary underground temperature of the mine. I might say we have not used much gunite for this purpose as there is very little trouble with slabbing in the cross-cuts. Most of our experience was in one cross-cut where the rock did slab off to some extent and in this working we found that where the rock was air sealed by the use of gunite, there was no trouble with slabbing.

We do not use structural steel for underground supports and therefore have had no experience with the use of gunite as a coating for steel.

Mr. G. E. Flanagan :§ I am surprised at the amount of square timber that is used. Could not round timbers be used as well? Is any of the timber salvaged?

*Howard N. Eavenson and Associates, Pittsburgh.

†General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

‡Manager, Cement-Gun Construction Co., Pittsburgh.

§Mechanical Engineer, Heyl & Patterson, Inc., Pittsburgh.

MR. ROBERT LINTON: The advantage of using square timber is that it can be framed more easily and accurately. Considerable round timber is used as well in drifts where the weight is not excessive and in stopes which are not too wide. There is of course some economy in the first cost of round timber where it can be used to advantage. Some timber is salvaged but not a great deal, since the timbers are used as a temporary support and the space between them is filled up as close to the stoping backs as is possible.

MR. G. E. FLANAGAN: Timbering of the stopes reminds me very much of what was called, many years ago, slow-burning construction for office, warehouse, and other similar buildings. It was claimed that this was even better than steel as a safe-guard against fire, the argument being that such heavy timber would not ordinarily burn rapidly enough to let the building down where they have fire departments. The timbering in the shaft described appears to represent precisely such slow-burning construction and I would like to ask why the fire spread so rapidly.

MR. ROBERT LINTON: The fire started at a point 2800 feet down, which was the same as if a fire were started at the base of a stack 2800 feet high. It was started by the accidental ignition of the inflammable insulation of a power cable which had gotten away from the electricians who were installing it. This very quickly created a hot fire which was communicated to the timbers and, with the strong draft which was speedily developed, even the heavy timbers burned quite rapidly. Water could not be applied to the shaft because, had this been done, it would have reversed the air current, converting the shaft into a downcast and carrying the poisonous gases of combustion back into the workings where there were still a considerable number of men. Ordinarily, a fire would not start with the intensity with which this fire started, and as a matter of fact shaft fires in timbered shafts are very rare considering the great number of such shafts which are in regular operation.

MR. G. E. FLANAGAN: How much dust is created in metal mining operation and is it one of the difficulties encountered?

Mr. Robert Linton: So far as volume is concerned, the dust problem is not serious. We keep a strong current of air passing through the mine for purposes of ventilation and cooling. It is not solely a question of providing pure air for breathing but, since the rock temperature on the lower levels is over 100 degrees, it is necessary to lower it artificially in order to enable the men to do satisfactory work. Further, the collar of the shaft is 6110 feet above sea level and the natural evaporation at this altitude has a cooling effect; while on the 3600 foot level we are only 2600 feet above sea level. Consequently, the advantage of rapid evaporation is lost and stronger air currents must be provided to keep men cool. This is a point which I think is frequently overlooked in planning ventilation for deep mines.

The flow of air is sufficient to remove the dust. It is not the quantity of dust but the character of it which is injurious. The dust contains particles of rock which are very fine and sharp, and, when breathed, irritate the delicate membranes of the passages to and through the lungs, developing a condition called silicosis. This is frequently termed miner's consumption and was for many years attributed to the fact that the men worked underground, until it was realized that the real cause was irritation by the fine rock particles. In all of our drilling work, where it is practicable to do it, we use drills in which a small jet of water passes through the hollow steel bit and thus keeps the drilling face wet. Such drills make no dust.

Mr. G. E. Flanagan: What percentage of the material broken down is raised to the surface?

Mr. Robert Linton: Since enough waste rock has to be provided to fill the stopes from which ore has been extracted, waste rock produced in development is used for that purpose so far as possible. The amount of waste rock varies with conditions. If an extensive program of development, such as cross-cutting in waste rock, is being prosecuted, the mine may produce more waste than is required for filling. If, on the other hand, the development work is largely in ore, then the mine may not produce sufficient waste and it is necessary to mine a

certain quantity of waste rock in order to get enough filling for the stopes.

Mr. G. E. Flanagan: I judge timber has to be brought very considerable distances out there and with the price of timber going higher all the time the cost will probably soon equal that of concrete.

Mr. Robert Linton: Naturally, the higher the price of timber the more nearly does the cost of timbering approach that of concreting. There is, however, still a considerable spread in first cost. The economy results from the greater permanence of the concrete construction.

Mr. Arthur J. White: Do you have a condition in your mines where the rock after it is excavated is under pressure and, when you apply the gunite to it, it will not hold? I was in Northern New York a couple of weeks ago and in the Shandaken tunnels being sunk there for the New York Board of Water Supply, they have a condition where the rock is under terrific stress and after the tunnel has been drilled, pieces flake off, which makes it very dangerous for the men working in the tunnel as these pieces of rock come with terrific force. They tried to use the cement gun to stop that flaking, but it was not a success. I was wondering if you had any such condition in your mine.

Mr. Robert Linton: No such condition has ever come under my observation either in Butte or elsewhere. Timbering and stope filling is for the purpose of supporting the weight of overhanging rock after the removal of ore.

Mr. Arthur J. White: I also understand that the Anaconda Company is using the cement gun to a great extent to combat mine fires. It is my understanding that they have as many as nineteen guns there.

Mr. Robert Linton: I do not know how many cement guns the Anaconda Company uses, but gunite is employed to a very great extent in its underground workings, both for fireproofing the shafts and for other purposes.

MR. J. R. ELLIOTT:* I would like to ask the average footage per shift in crosscutting.

MR. ROBERT LINTON: We frequently average over five feet per round broken for all cross-cuts driven during a week. The actual advance per shift varies with the position of the work, the length of haul, and other factors chiefly connected with handling the rock after it is broken. Over half of the total labor underground is employed in handling the broken ore and waste rock, and it is this part of the work which is hardest to speed up. Owing to the limited size of the workings, mechanical loading possesses little advantage. In spite of this, the deeper rounds are a decided economy. It means saving in powder and drill steel and the time required to set up and take down the drill is spread over a greater footage.

MR. H. N. EAVENSON: I was a little surprised at the statement that the use of concrete over timber is justified in shafts, if they have a life of only ten years. Of course, they are very much smaller than coal shafts but I do not think any man starting a shaft for coal with a life of only 10 years would have either money or nerve enough to put in a concrete shaft. We would not have had a chance to put in the Tug River shaft mentioned if it had had a life of only 10 years. That had a life of 40 years or more. I doubt if concrete shafts would be justified in a coal plant under 25 or 30 years.

MR. ROBERT LINTON: That is probably about right, because the rocks overlying coal measures do not require the strong bracing which is usually necessary in the western metal mining shafts, since these are usually sunk through rock that is more or less shattered. Where shafts are sunk in an unbroken sedimentary formation which parallels the conditions in coal mines, the life of the mine would have to be longer to justify the concreting. I know of one shaft which was sunk through limestone over 12 years ago, and has up to date required very little repair. The average of 10 years was based on conditions which usually prevail in metal mining.

*Baton & Elliott, Engineers, Pittsburgh.

Mr. J. W. Paul:* I have been very much interested in the paper. The speaker has made quite a contribution to the literature of the Society and has brought in some new phases of the use of concrete that some engineers in this section of the country are not in touch with, since conditions in metal mines are very different from what we have in coal mines. He has referred to certain uses of concrete in metal mines, which have come into very general use in recent years in coal mines and that is the use of the cement gun in roof protection. That is being done very successfully in the manner he has related. We have used it in our experimental mine. Some cement put on with a cement gun has been in place five or six years, during which time it has been subject to the pressure of probably 150 mine explosions. The important thing in the application of it is to make sure that there are no voids back of it through which air or moisture might disintegrate the material and thus cause swelling that will force the cement off the surface. In a great many instances we have not been required to put on a mesh. Often by driving a few pegs or nails in the shale, the coating of cement will adhere. We have been very successful, without the use of wire mesh, in putting it on boards, especially on ordinary rough sawed boards, if they are first made wet.

Mr. S. L. Goodale:† I was wondering about the steel in the shaft construction. Is that more or less subject to acid in the mine water, and would that not get through the concrete, and are any precautions taken to prevent possible corrosion?

I was very much interested in the slow-burning construction that was proposed some time ago, but one of the important matters in that connection is that the heavy timbers should be not only heavy but also planed, and that would bring in an item of expense hardly warranted in mine work.

Mr. Robert Linton: The steel framework in the shaft was used primarily to support the ground while the concreting was being done. The structure derives its strength chiefly from

*Chief, Coal Mining Investigations, Pittsburgh Experiment Station, U. S. Bureau of Mines.

†Professor of Metallurgy, University of Pittsburgh, Pittsburgh.

the reinforced concrete. In the nature of the case it would be impossible to make observations of the reinforced bars for the purpose of watching corrosion, but with the concrete once set and backfilled, the rock pressure would be distributed over the entire monolith in such a way that the concrete would probably be sufficient to resist any pressure against it even if there should be corrosion of some of the bars. I regard it, however, extremely unlikely that any corrosion would take place since the shaft is some distance from the ore veins, and even if water should seep into the concrete, I think it is not of a character to have any injurious effect on the bars.

It would not add very greatly to the expense if the timbers were planed but, even if this were done, I do not believe it would retard a shaft fire after it had once attained any headway. By far the best plan is to coat the timbering with gunite and when this is done the shaft can be considered entirely fireproof.

Mr. Fred. Crabtree:* Mr. Linton's paper has touched upon several matters of considerable interest to me personally. Having heard and seen numerous references, all more or less general and indefinite, to the use of gunite, I was glad to hear of Mr. Linton's experience with it. His description of the use of concrete in shaft and mine construction was also very instructive to any one who has followed the efforts to insure the greatest possible safety for miners, and who remembers the loss of life due to fires in timbered mines.

Equally interesting was his account of the standardization of methods of drilling, the use of instruction cards, and of the protractor and framed wire screens for studying or illustrating the spacing and alignment of drill holes. Similar screens have been used in the mining laboratory of the Carnegie Institute of Technology, but without the protractor for accurately determining the angles of the drill. The methods described by Mr. Linton illustrate the phases of the most advanced type of mine management and similar methods could be used to considerable advantage in this district. It may not be out of place to say that the Mining Department of the Carnegie Institute of Technol-

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ogy will have next year a research fellowship for investigating in conjunction with the United States Bureau of Mines, the methods of blasting coal and the problems involved in determining for each mine the best conditions for getting the most satisfactory results in shooting the coal. There is much to be learned along these lines, in coal mining as well as in metal mining.

MR. W. A. WELDIN:* It occurred to me that it might be interesting to say something about the trouble engineers have been having in this district with aggregates for concrete. It used to be sufficient to specify "clean sharp Allegheny River sand." Now conditions in the river have changed, or we have learned more, and that is no longer sufficient. In our office we have made up our minds that for all concrete work we must subject the sand to a color test and the gravel to close scrutiny. I suspect we have not yet arrived at the proper aggregate specification. Concrete failures by disintegration and inherent weakness are far too common the country over and it behooves the engineer, whether using concrete on the surface or underground, to be cautious.

The shafts described by Mr. Linton are all rectangular. The coal mining men around here like to see curves in the outline of the shaft section, but the size of the shafts may have something to do with it. What is the greatest width of those shafts?

MR. ROBERT LINTON: The dimensions of the Granite Mountain shaft are shown in Fig. 4. The dimensions of four-compartment shafts used in most metal mines will not vary a very great deal from this. The Alpha shaft of the Consolidated Coppermines Company, at Kimberley, Nevada, is 12 feet by 19 feet, four inches, outside diameter. This has five compartments and, being sunk through the limestone where there is little weight, has been very easy to maintain.

MR. W. A. WELDIN: That is a longer span than many coal shafts. I imagine you must have weep holes to take the water pressure off the lining; or do you make it tight?

I have also been interested lately in the question of surface

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support. Where the land above the mine is valuable what can we do if there is a movement of the strata? Possibly the filling of rooms by the flushing method would provide the most economic method of support. I wonder whether anything would be gained by mixing cement with this filling and making a lean concrete of it.

Mr. Robert Linton: Weep holes were not used in the construction. However, at several points where bearers were run out from the walls of the shaft to the solid rock, water pipes were run through the concrete and the water carried down to the station below or to some point where the water could be properly discharged. This was done by way of precaution as probably all of the water percolating through the formation would flow down and enter the shaft in that portion which lies below the concreting. Had the shaft been concreted solid from top to bottom, it would have been advisable to leave a few weep holes to facilitate the escape of the water.

Where the stopes are carefully filled, as at the Butte mines, there is usually not much trouble with subsidence. This subject is now being given special study by a committee on ground subsidence of the American Institute of Mining and Metallurgical Engineers. Mr. H. G. Moulton is chairman of that committee and the final report will probably afford some very definite information. Introducing mill tailings or other fine material by flushing provides a very compact filling for the stopes. I do not know whether or not there would be any material advantage in mixing cement with such filling.

Mr. F. A. McDonald:* In connection with my work I have lined several mining shafts and slopes with concrete; in fact, I was engaged in sinking two concrete-lined shafts and a slope near Brownsville at about the same time the Tug River shaft was being sunk. One of these Brownsville shafts (the work on each was being performed by the Dravo Contracting Company) was in quicksand and had to be sunk on a shoe. Without knowledge of this fact, the shaft was started in the usual manner but after it had reached a depth of 25 or 30 feet, the contractors

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were unable to brace the sides, owing to the great pressure on the hillsides which crushed the timbering and sheathing. It was necessary to fill the hole completely and build a shoe upon which the concrete lining was built in forms, and then let the whole lining settle by undermining the shoe. This method was used until solid rock was reached when the remainder of the shaft was completed in the ordinary manner.

In the earlier days we had considerable trouble with the scaling off of the concrete, especially with curtain walls which were thin, and in many cases both curtain walls and shaft lining required considerable repair. I believe that this trouble was largely due to the lean mixtures and the character of the materials used. At that time a 1-3-6 mixture was considered satisfactory but at the present time a 1-2-4 mixture is considered none too good and great care should be exercised in determining the quality of materials used.

Concrete makes a very satisfactory lining for shafts and I believe that any mine having a life of from 15 to 20 years would be justified in its use.

Referring to the use of the cement gun, reports of the results obtained from its use have been so contradictory that I do not believe any set rule for its use can be accepted. Thus far, I have not had any practical experience in the use of the cement gun for inside mine use but I believe that at any large mine an equipment of this kind will justify itself for general use both inside and outside, the extent of its use inside being determined by local conditions.

The method of shooting of coal and rock is important and is receiving considerable attention and study, as the different kinds of coal and strata found in the Pittsburgh district require different powders and different placings of poles to secure the best results both as to safety and as to quality of coal produced. Generally speaking, the old-fashioned black blasting powder produces the best grade of coal but since the introduction of permissible explosives it has been necessary to do considerable experimenting in order to secure a grade of the permissible powder which will secure results approximating those secured by the use of black powder.

Mr. Edward Steidle:* Mr. McDonald's remarks brought to my mind several examples of concrete work in shafts, which may be worthy of mention. Concrete curtains in at least two concrete-lined shafts in the Pittsburgh district have failed and peeled off. The concrete was poured in the usual manner and was supported on six inch I-beams, placed on five-foot centers. Reinforcement was affected by one-half inch round iron rods on six-inch centers between the horizontal members. The mixture in one case was 1-2-4. Those in charge of the management believe the failure of the concrete is due to the difference in temperature in the air and hoisting compartments. Improper sand may have been used. In any event, in one case they are tearing out the concrete and building a brick curtain.

Mr. Weldin mentioned the matter of concrete supports for underground workings. They are breast stoping the "sheet ground" deposits of the Joplin district, Missouri. The cover ranges in thickness from 100 to 300 feet and pillars of ore are left as a support for the roof. One company attempted several years ago to support the roof temporarily with concrete bulkheads while the ore originally left in pillars was mined. The concrete bulkheads were about 15 feet in diameter and were poured from the surface through bore holes. I understand that this application of concrete was unsuccessful due to excessive cost and failure to get proper contact between the bulkhead and the roof. This also brings to my mind a mine up the Monongahela River in which an explosion occurred in 1916. The company had attempted to support the roof in one of the main entries by the use of concrete posts one foot square. The posts were poured between props which were subsequently removed. The force of the explosion knocked down every concrete post but did not disrupt the few props which had been left in place. No doubt the concrete had shrunk while setting and the posts were not carrying weight.

It is probable that under average conditions concrete supports would be too costly. Under any circumstances timber would have to be used in conjunction with the concrete supports or a special method of grouting employed to effect proper contact with the roof.

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POWER-STATION DESIGN

By C. W. E. Clarke*

LOCATION

The existence of a market for the sale of electric energy in a given locality fixes in general the location for a power development. The present-day economy and reliability of high-tension electric transmission permit considerable latitude in the selection of the exact site. Not many years ago it was imperative to place a power-station at or near the center of distribution so as to avoid as far as possible the excessive losses and varying voltages resulting from low-voltage transmission for any considerable distance. These factors led in the early days of the industry to the construction of many small non-condensing plants scattered over extensive distribution areas. As transmission voltages increased, these scattered stations were gradually converted to sub-stations and were supplied from larger and more efficient generating stations. To-day the location of generating stations with reference to the distribution areas is of minor importance, though it is of course desirable that the length of transmission lines be kept down to a minimum. Atmospheric disturbances and the increased liability to physical accidents resulting from long transmission systems make it desirable to place the generating station as close as possible to the distribution area.

The controlling factor in the selection of a power-station site is the existence of an adequate supply of water for condensing purposes at all times. The determination of such a site involves a careful study of the hydrographic records, and a consideration of the possibility of water storage and recirculation. The proximity of railroads or other lines of fuel supply are matters to be considered, but these factors cannot be looked upon as controlling the location of a site since railway connection can be built at a comparatively low cost. It is plain then that the one factor governing the selection of a power site is a supply of condensing-water.

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Much has been said in recent years, regarding the great advantage of the so called "mine-mouth" power-plant. The only advantage in so locating a plant is a saving in the cost of fuel handling, and there are in most cases disadvantages which almost, if not entirely, offset this saving. There are very few locations where condensing water is available in any large quantity at the mines, and the water available at such locations is frequently badly contaminated. These facts limit the available "mine-mouth" locations to a very few. Again, the construction and maintenance costs of long systems for the transmission of large quantities of power may frequently offset the gain in fuel cost. Such systems must be elaborately protected against the elements and, at best, are subject to frequent interruption during the summer months, unless expensive duplicate lines are installed.

The general proposition of placing steam power-plants at every available location in the coal district, and running an extensive network of transmission lines to the various load centers, is not of necessity a good one and investigation will show that in most cases proximity to the distribution area should be considered before proximity to the mines.

The Colfax power-station of the Duquesne Light Company may be looked upon as one of the relatively few plants located at the mine which is entirely successful from the viewpoint of choice of location. Several factors combined to make this plant the success that it is. The distribution area of the Duquesne ring is so situated as to make its position of distinct advantage in balancing the feeding of an already existing distribution system. The water-supply in the Allegheny River is not contaminated to such an extent as to render it unsuitable for use in surface condensers and is sufficient for a development of 300,000 kilowatts. This is as much load as could advantageously be generated at that point.

As a general rule, the larger power markets are located near rivers, or other large sources of water-supply, as manufacturing industries and large cities are usually so located. However, there are enough exceptions to this rule to make proper water-supply a serious problem in many cases.

GENERAL FEATURES OF DESIGN

The general form and lay-out of a power-station building will to some extent be affected by the ground conditions and water-levels. The condensers must be located at a level which will permit pumping water against as little static head as possible, also so as to allow of siphonic action in the discharge. In cases where the water-level varies only slightly, the turbine-room basement floor may be placed at or even below the normal water level. If there are great fluctuations in water-level, special arrangement must be made to meet the difficulty.

The cross-section of the Colfax plant is an example of adapting general design to local hydraulic and terrain conditions. The general water-level in the Allegheny River is about 721 feet above sea-level, with occasional increases to as high as 748.5. The turbine-room basement floor had to be placed low enough so that the suction head on the circulating pumps would not exceed a practical maximum, the circulating pumps being located at an elevation of 732.5. This floor was placed at 725, slightly above the mean low-water line, but 29 feet below grade. The floor of the boiler-room basement was placed at grade to facilitate ash-car handling, and for general symmetry. In the case of the Seward station, but little excavation was required to place the condensing-water pumps at a proper level, hence the turbine-room basement floor is but eight feet below grade. Placing the boiler-room basement at grade for the same reasons as held at Colfax brought the boiler-room floor level with the turbine-room operating floor. The turbine room should, of course, be placed next to the water to minimize the cost of constructing intake and discharge tunnels for condensing water. The boiler room should be located adjacent to the turbine room to simplify steam piping as far as possible.

It has been quite general practice in the past to place the switching apparatus on the opposite side of the turbine room from the boiler room and to have an operating room from which the engine or turbine room may be seen. This is largely a relic of the days when switching apparatus consisted of a switch-

board, and communication between engine and switchboard operators was by word of mouth and manual signals. To-day there is little if any need that the switchboard operator be able to see into the turbine room. The electrical apparatus and control room may then be located where convenience in other respects dictates.

BOILER ROOM

The best arrangement for a boiler room is probably secured by placing the boilers in two rows facing a common firing aisle. Weighing larries can be run along this firing aisle and because all larries run on the same pair of rails the number can be kept at a minimum. Bunker construction as well as the coal handling and distribution system may be made very simple. Any arrangement of cross aisles simply increases the floor space required and the complication of coal handling and storage systems; also, the steam piping may be simpler with the parallel double row arrangement than with any other. The space between adjacent boilers should be large enough to permit proper operation. At Colfax the boiler columns are placed 12 feet apart. The single firing aisle makes supervision simpler, as all boilers can be seen from a single point.

The type of stoker selected must depend upon the characteristics of the available fuel. For the coal generally found in this part of the country the underfeed stoker is best. Low-volatile, non-coking coals require overfeed or chain-grate stokers.

The use of double stokers—that is, two stokers placed face to face—is seldom of advantage. In cases where the boiler heating surface per square foot of floor area is very great this stoker arrangement may be justified, though it is probable that a careful consideration of all the conditions will show that the single stoker is better. The double stoker, when used with a parallel double row of boilers, necessitates three firing aisles with the consequent additional supervision, bunker and coal handling equipment. This type is justified when it is expected to operate boilers at very high ratings. Such operation should be considered only on systems having a very low load factor and a short high

peak. In the case of a boiler plant supplying steam for heating, in which there will be short periods of very high demand due to extremely cold weather, the double stoker is the proper thing. Periods when the temperature falls far below the normal for which a plant would be designed are usually of comparatively short duration and it is good practice to handle such peaks by driving boilers to a high rating rather than by installing extra capacity to carry them on medium ratings.

The use of pulverized fuel has only just passed the experimental stage. There are several apparently successful installations and there is little doubt that this system will be used in many of the plants built in the future, especially where only low-grade fuels are available. It has many advantages over other methods of burning coal. Combustion can be made virtually complete, as a much more perfect control can be accomplished than is practically possible with any type of stoker. There is very little ash to be disposed of, as most of the solid products of combustion are carried up the stack. This feature is decidedly objectionable in any thickly settled district and should be given careful consideration in the light of existing and probable future local regulations regarding smoke, etc.

Despite the foregoing advantages in efficiency and operating simplicity the additional cost of the system may make it inadvisable. The pulverizing and handling equipment is expensive and such a system should be chosen only after careful consideration of the ultimate efficiency from a financial viewpoint. Engineers too often fail to give sufficient consideration to the final operating cost which must include all fixed charges and maintenance. It will frequently be found that a slightly less efficient system will offer a saving in cost which will more than offset the gain in thermal efficiency.

Oil is the ideal fuel for use under boilers, but, with the present relative costs of coal and oil, it cannot economically be used for power-station work except in certain localities. Such localities are not sufficiently numerous to make the use of oil fuel in power-stations of frequent occurrence. In designing fuel-oil boiler furnaces serveral features require special attention. The combustion space must be large and so shaped that the flame from

the burner will not impinge directly on the brickwork. In general, furnace temperatures are higher with oil than with coal so that particular care must be used in selecting the fire-brick.

There are two general systems for oil burning. In one, the oil is carried to the burner at low pressure, from one to four or five pounds per square inch, and blown into the furnace by a steam or air jet. In the other, the oil is under high pressure and is sprayed into the furnace by virtue of its own pressure. The low-pressure system is always preferable for power-station work. The oil-feed piping to the burners should be arranged for continuous circulation to avoid stoppage of the pipes. A heater must be installed to preheat the oil, as in cold weather all but the lightest oils will have a very high viscosity. Special regulations relating to the handling and use of fuel oils exist in practically all localities and will govern, to a certain extent, the detail of any given installation.

Each boiler should be provided with a complete set of instruments located upon an instrument board close to the boiler and where the stoker controls are mounted. In some cases it may be desirable to place all load indicators (steam-flow meters or feed meters) on a single centrally located board so that the boiler-room foreman can keep better track of boiler-room operating conditions. This applies particularly to plants having relatively small boiler units. Some form of CO_2 recorder should be installed, though up to date none of them is as satisfactory as could be desired. There are many boiler control systems on the market but they should be purchased only after a careful consideration of their real merits. Automatic damper and furnace control is desirable but should be chosen with extreme care as many of the systems obtainable do not accomplish what is claimed for them.

Motor drive is usually best for the stokers though it necessitates the provision of direct current for proper speed control.

The particular arrangement of the coal-handling system will depend upon local conditions. Usually the coal must be raised from at or near ground level and a skip or bucket hoist is well adapted to this work. Crushing apparatus may be located at the upper or lower end of the hoist but usually it is better to place it at the bottom to avoid as much as possible the production of dust

within the station building. For horizontal conveying there is nothing better than a belt conveyor, and it may also be used for elevating under certain conditions, provided the inclination is not greater than 20 degrees.

ASH HANDLING

The method of ash disposal must be designed to suit local conditions. Ash hoppers, if used, should be large enough to hold the ash from at least 12 hours' operation. Various systems for depositing the ash directly in water have been used, but such a system involves construction and operating expense not usually warranted by the advantages. Ordinarily, large hoppers under which standard railway cars may be run constitute the best arrangement for ash disposal. Hoppers should be equipped with large sliding gates operated preferably by steam or air. The use of small gates results in arching of the ash which necessitates the use of a slice-bar to dislodge it.

The space in the boiler-room basement beneath the firing aisle may be used for machine-shops, storage rooms, toilet and wash rooms, etc.

With the advent of large boiler installations the supply of air for the furnaces becomes a problem requiring careful consideration. It is a good practice to conduct the air discharge from the main generators to a duct from which the draft fans take their supply. This, however, will furnish, at best, less than half the necessary air. In the past it has been common practice to draw air directly from inside the building. With large boiler units the quantity of air so required becomes so great as to make it extremely difficult to keep the building warm in cold weather. In the large so-called super-power stations it becomes necessary to provide means for taking furnace air directly from outside the station, at least in very cold weather. This may seem at first sight to be a step in the wrong direction—bringing cold air to the furnaces, when we find air preheaters being installed in some stations—but, unless heat which would otherwise be wasted can be used for preheating this air, it is more economical to heat it directly in the furnaces where the efficiency of the

heating process approaches 100 per cent., than to heat it with steam produced at the expense of boiler and furnace losses, or to heat it with flue-gases and use power to make up for the lost draft capacity in these gases.

ECONOMIZERS

The installation of economizers with fuel costs at their present level is of doubtful advantage.

When increased building, economizer, induced-draft fan, piping, maintenance, and operating costs are considered it will

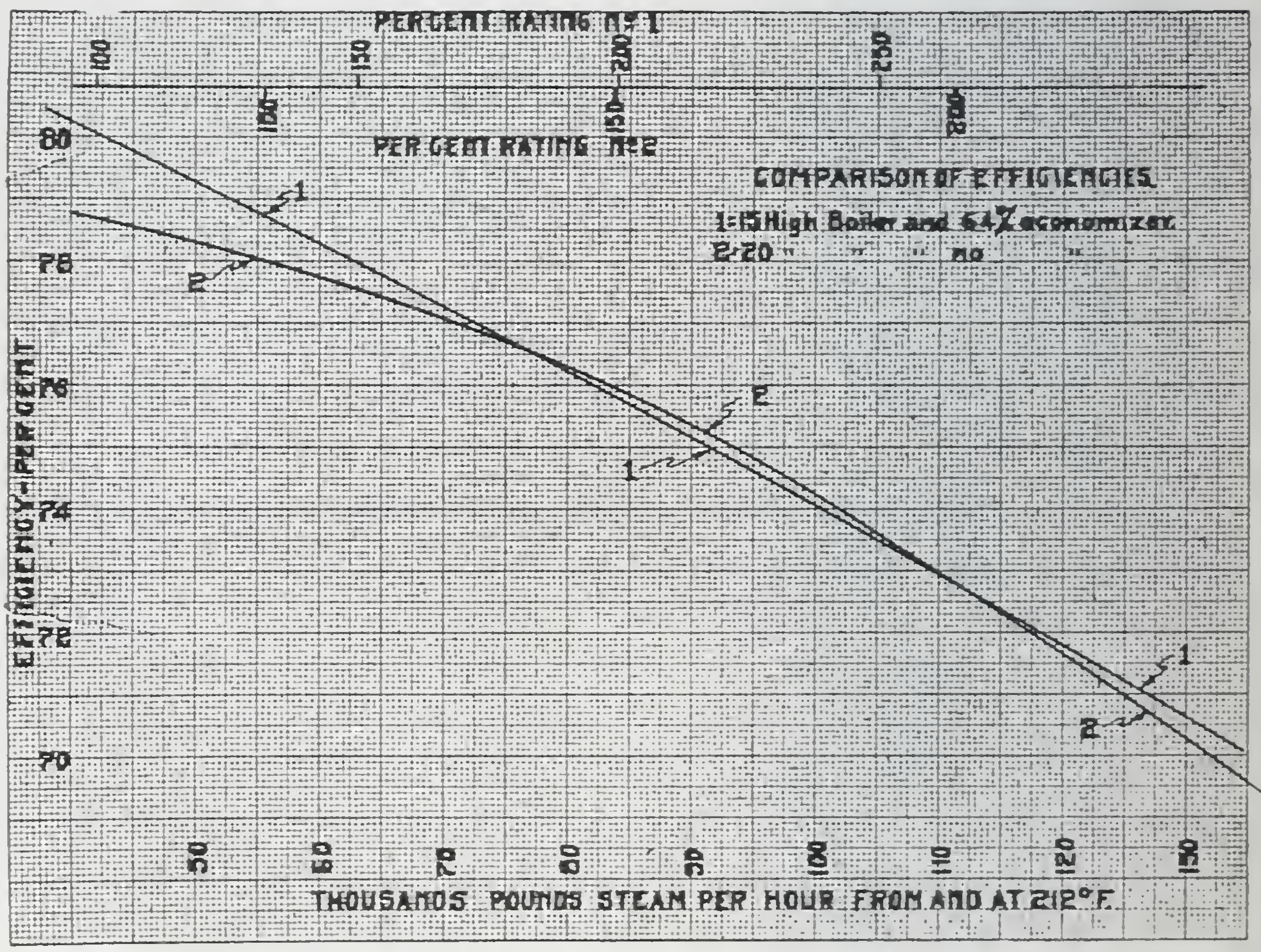

Fig. 1. Comparison of Boiler and Boiler-Economizer Unit.

usually be found that an increase in the height of the boiler will result in a greater operating efficiency, considered financially, than if economizers are used. The curve in Fig. 1 shows a comparison between the efficiencies of a 15-high boiler with 64 per cent. economizer and a 20-high boiler with no economizer. Every case

should be considered in the light of its own peculiar conditions but this curve is illustrative of the general trend.

Flues and uptakes may be built of steel plate and should be large enough to keep the gas velocity below some forty feet per second. Provision should be made for the holding and disposal of soot accumulations in the flues. With some grades of coal this accumulation is considerable and may cause great inconvenience if means for its ready removal are not provided. A steam-jet, vacuum-conveying system discharging the soot into the boiler ash-pits is a satisfactory method of disposal. The flues, if very large, are best located on the roof outside the building, as the expense of increasing the building height to cover them is not warranted. They should be covered with insulating material and a protective coating, preferably of sheet-metal, placed over the insulation to protect it from the weather. Arrangements should be made, of course, to take care of the expansion of the flue system, but the expansion joints provided should be as nearly gas tight as they can be made, as should all seams and joints in the flue system. Care should be taken to support the flue so as to avoid any buckling tendency. Though such a tendency might not become superficially evident nor cause any physical damage it would most certainly cause leaks and decrease the draft.

Stacks should be designed for gas velocities not greatly in excess of 35 feet per second. A steel stack should be insulated with a brick lining for its entire length. Self-supporting steel chimneys are preferable for power-house work as they can be placed on the power-house structure.

BOILERS

The particular type and size of boiler for any particular case must be chosen after consideration of the conditions peculiar to the job in hand. As a general proposition a boiler having straight tubes, easily renewable, is preferable to types having bent tubes. For high-pressure work (250-350 pounds) wrought steel is probably the only safe material for headers. The advantages of superheated steam are so well known as to need no comment.

Boiler settings at Colfax were built entirely of firebrick

and for large units this procedure seems fully justified. Steel casing should be used with insulation between the casing and the setting. This prevents air leaks and tends to keep the settings at a more uniform temperature as well as to minimize radiation losses. Special arrangement should always be made to prevent the adhesion of clinker to the setting. Practically the only way to do this is by ventilated blocks of some sort in the furnace walls at the points where the clinker forms. Too much care cannot be exercised in placing this tile, since if it is not properly set more harm than good will come from it. It must be bonded back into the furnace wall so that the blocks cannot fall out into the furnace. The use of steam jets in the furnace, though an effectual way of preventing clinker adhesions, requires a very considerable quantity of steam and is therefore not economical.

Clinker grinders should be used in large boiler installations. They should be so designed as to be capable of continuous operation, thus removing the ash as fast as it is formed, maintaining a constant bed of cooling ash somewhat above the crusher plates. The types of clinker grinders obtainable to-day leave much to be desired, but the increasing number of installations will doubtless lead to the development of good equipment.

For forced draft supply, a few large fans feeding into a general duct system are for several reasons better than one or two small fans for each boiler. They occupy less space, require less manipulation and use less power. Draft to individual furnaces may be controlled by dampers, thus permitting the fans to be run at practically constant speed for a given load.

There is little choice among different makes of large turbines for power-station work. There are only three manufacturers in this country who build large turbines, and they are all much the same in economy. There is quite a difference in the space required for the different types but all of them occupy a floor space (excluding the generator) less than that required by condensers and auxiliaries. There is some difference in length which may or may not be a controlling factor in a given case. The size of the units will of course depend upon the load characteristics of the system to be supplied. If there is a heavy base load the largest units should be installed to handle it. In design-

ing a new station the most thorough study should be made of past load conditions, and future conditions should be anticipated as far as possible so that provision for a proper expansion will be made in the original design.

Surface condensers are usually to be preferred to jet condensers because the pure condensate is available for boiler-feed purposes making elaborate systems for water treatment unnecessary. If there is a supply of good boiler feed-water available (and this is rarely the case) a jet condenser is about as economical financially as a surface condenser. The surface condenser is more expensive in first cost, and in maintenance cost requires more attendance and much more power for operation. The quantity of heat saved in the condenser is very small and may quite easily be saved in a jet condenser by installing a small pre-condenser in the exhaust openings from the turbine and circulating the cold boiler feed-water through it.

There is never a case where it is safe to take condensing water directly in without some sort of screen to remove leaves and other matter. For this purpose a traveling screen is the only suitable apparatus. These screens should be mounted in wells provided with gates or stop logs, so that the water may be shut off and the well pumped dry in case of necessity. Screens are usually so constructed as to permit their being lifted out entirely for repairs of a major character.

The water velocity through the free opening of screens should not exceed two feet per second, unless such a velocity requires extraordinarily large screens. There should always be a house over the screen, well provided with means for heating it in cold weather.

The tunnels within the station should be of ample size. Velocity in the intake tunnel should not exceed three, and in the discharge five, feet per second. Many of the older power-stations in which large reciprocating units were operating were able to install turbines and increase their capacity three or four hundred per cent. because the condensing-water tunnels were made large in the original design. Plain rectangular tunnels are always the best. Special elliptical or arched tunnels are of no advantage, and always cost more.

Arrangments should be made so that part of the condensing water can be recirculated from the discharge to the intake, as this will, to a great extent, prevent trouble from ice in cold weather.

The only method left for improving the overall efficiency of a power-station is through the system of heat conservation which goes under the general title of the "heat balance system." Boiler design has reached a point beyond which little can be expected. Turbine generating equipment gives us efficiencies about as high as we can look for. We are, then, faced with the proposition of making the system of heat utilization in the station as efficient as possible. At best, there is only a little over 30 per cent. of the energy put into the steam by the boiler which is available for conversion into power. The problem is how to approach as close as possible to converting all this energy into power. This can be accomplished only by retaining in the station heat cycle as much as possible of the latent heat of the steam which ordinarily is transferred to the condensing water. A heat balance system has this object in view.

It has been the general view in the past that the efficiency of steam-driven auxiliaries is of no importance because all the heat rejected by these machines is recovered by using the exhaust to heat the feed-water. Any heat which is available for conversion into energy should not be used for feed heating unless other factors, such as reliability, demand it. It will be seen from the foregoing that steam-driven auxiliaries should be kept down to the minimum demanded by the requirements of absolute reliability. In case the auxiliaries installed do not furnish sufficient exhaust steam for feed heating, steam may be bled from the main unit to make up any deficiency. This will not usually be found necessary.

There are four general methods of heat balance:

1. Mixed steam and electric drive for auxiliaries.
2. House turbine, alternating current or direct current and electric drive for all but enough of the auxiliaries to keep the station running in case of accident to the house turbine and main generator.

3. Steam drive for part of the auxiliaries and bleeder connection to main unit to make up deficiency in steam for feed heating.
4. All auxiliaries driven electrically from main bus, and steam for feed heating bled from main turbine.

The first system mentioned is entirely satisfactory for the smaller stations, as a fairly close proportioning is possible, and any system of the type described under 2, 3, or 4 would usually be too elaborate and expensive to warrant its installation.

The writer believes the second system to be the best for large stations. It is the type used at Colfax and its ease of operation and capacity for close regulation in actual service have fully justified its installation.

The third system is in use in some installations but the writer does not consider it as good as the second method, from the viewpoint of reliability. Any accident which cuts off the energy supply to the main bus leaves only a small part of the auxiliaries available for use, while with the second scheme, unless the house turbine has shared in the shut-down, all auxilaries are available. Any accident so severe as to put both main bus and house turbine out of service would probably render the whole station inoperative.

The last method is the most efficient but is open to the objection that in case of a shut-down of the main generating equipment there is no way to keep the auxiliaries running. It is necessary then to provide some source of auxiliary power that is independent of the main generating system and main bus system.

Reciprocating engines for auxiliary drive are not advisable in any case. They are wasteful of steam and require a great deal of oil and attendance. For electric drive, squirrel-cage induction motors should be used wherever possible. Of course slip-ring motors must be used when the apparatus is to be started under load.

A good many engineers advocate the use of direct-connected exciters but in my opinion there are a number of factors in favor of a separate exciter system. An exciter bus is necessary

in any case on account of the possibility of a burn-out or other accident to the exciter. It would be poor practice to permit, say, a 20,000-kilowatt unit to be dependent upon the integrity of a single 200-kilowatt exciter when such a practice is not necessary. A direct-connected exciter is subject to all sorts of minor difficulties, such as broken brushes, dirty commutator, loose brush connections and many other troubles not in themselves serious but sufficient to render the machine useless as an exciter for appreciable periods. I have known of cases where the exciter brackets were broken off by vibration of the turbine unit. A separate exciter system with duplex steam and electric drive for the generators costs more money but may easily repay its extra cost by avoidance of minor shut-downs in a year. The duplex drive is also useful in heat balancing as the load may be carried on either the motor or turbine end as required by the exhaust steam demand.

INSTRUMENTS

The matter of providing proper instruments is usually given too little attention. Much money is spent, and instruments are installed at many places where they are not necessary and left out where they are of great importance. The designing engineer should plan quite completely how the water and thermal balance is to be worked out in the station and from this plan provide instruments to give the necessary data for a complete balance. The importance of such an operating balance cannot be overestimated. If heat units and water were always looked upon by executives as dollars and cents, books would be kept as carefully as a concern's financial books. Usually, however, if a station delivers or appears to deliver a satisfactory amount of output for a given quantity of fuel, little attempt of an organized nature is made to check this up or to find means for improvement. A regularly kept thermal balance is the only means by which an operator can understand what his plant and its component parts are doing, and a thermal balance can be arrived at only with the aid of a sufficient number of instruments properly placed.

PIPING

The lay-out of the piping system in a power-plant is a very important element of design and one that is usually given insufficient attention. At best there must be a tremendous amount of it but it should be made as simple as a careful study throughout the entire design will permit. At the very outset the designing engineer should have a fairly clear conception of what the piping scheme is to be down to the minor elements of gland-water and drip piping. These latter systems are too often left to be cleaned up last and consequently are thrown in largely by the piping gang in the field.

The controlling element in the piping scheme must of course be the main high-pressure steam system. This must be kept simple and straightforward, partly to avoid friction losses, but more particularly to enable the operating men to grasp the entire system readily so that in case of trouble they will have no hesitancy as to what to do. Elaborate cross-connection and by-pass systems may seem very fine on paper. To be able to use any boiler or set of boilers to feed any section of the plant, other things being equal, is advantageous; but when such an arrangement requires complicated valve and piping systems, they may do more harm than good in operation. Every foot of pipe and every fitting beyond what is actually necessary is only another hazard where failure may occur. It should be remembered that plants are built to operate—not as an exhibit. All valves should be easily accessible and not placed under or behind apparatus, which in case of trouble might make it impossible to reach them.

The main valves for controlling the high-pressure system should be motor operated with a control station near the valve and another at some protected location outside the boiler room. This second station would be a lock station for use only in case of emergency. Lock stations provided with glass windows, to be broken in emergencies, can be secured for motor-valve operating systems.

Provision for expansion should be given special attention. For this purpose large double S or U bends should be used and

they should be as large as practicable. The minimum radii as given in the tables for expansion bends should always be exceeded. Expansion systems which put torsional stresses on the piping should never be used with high pressures and temperatures.

In modern work, pipe sizes for high-pressure work are usually determined on a basis of steam velocity rather than upon pressure drop. Computations of the pressure drop in a piping system full of bends and fittings are not even approximate. In high-pressure work, velocities should be kept below 10,000 feet per minute while with low pressure they may run up to fourteen or fifteen thousand.

Pockets where water can collect should be avoided and all low points provided with drip conections. The drip system should be given careful attention. A general header should parallel the steam header and be carried to an accessible point where the traps or other means for disposing of drip may be located. Traps should not be stuck away in corners but placed where they will get regular and frequent inspection as they are, at best, sources of considerable trouble. There does not seem to be on the market to-day a trap suitable for high-pressure, high-temperature work. Check-valves should be provided on all drip connections, as well as globe-valves. It seems needless to say that all drips should be returned to the boiler feed system at some convenient point.

The remarks as to simplicity and accessibility of the high-pressure system apply as well as to the exhaust piping.

The water system, though not requiring the care in design demanded by the steam piping, should be carefully thought out and kept as simple as possible.

In general, valves on all piping systems should be easily reached or, when this is impossible, provided with chains for their operation. All large valves used for regulation should be motor operated while those which are used either fully open or fully closed may be operated with hydraulic cylinders.

PIPING SYSTEM MATERIALS

In Table I (folding plate) is given a summary of the piping materials best adapted for use in power-station work.

TABLE 1. PIPING AND FITTING SCHEDULE FOR MECHANICAL EQUIPMENT*

	Pipe	Fittings	Valves	Gaskets	Flanges	Bolts
[illegible]	2-in. and under, E. S. steel 2½-in. to 12-in., F. W. steel 14-in. and over O. D., steel, ⅜-in. thick	1¼-in. and under, E. H. screwed F. S. 2-in. to 12-in., E. H. flanged C. S. 14-in. and over, E. H. flanged C. S. (special parts)	1-in. and under, E. H., F. S. and "Monel" threaded 1¼-in. to 1½-in., E. H., C. S. and "Monel" (O. S. & Y.) threaded 2-in. and over, E. H. flanged C. S. and "Monel" (O. S. & Y.) 6-in. and over, to be fitted with by-pass	Compressed asbestos $\frac{1}{16}$ in. thick, such as "Durabla" or "Tauril"	2-in. to 3½-in., E. H. F. S. welded to pipe 5-in. and over, E. H. F. S. Vanstone	Special oil-heat-treated with nuts on each end
[illegible]	2-in. and under, E. S. steel 2½-in. to 12-in., F. W. steel	2-in. and under, E. H. screwed C. S. 2½-in. to 12-in., E. H. flanged C. S.	2-in. and under, E. H. screwed C. S. and "Monel" 2½-in. and over, E. H., C. S. flanged and "Monel" (O. S. & Y. pattern) 6-in. and over, to be fitted with by-pass	Compressed asbestos $\frac{1}{16}$ in. thick	2½-in. to 5-in., E. H. F. S. welded to pipe 6-in. and over, E. H. F. S. Vanstone	Standard steel
[illegible]	3-in. and under, I. P. S. brass 1½-in. and over, F. W. steel	2-in. and under, E. H. screwed cast-iron. 2½-in. and over, E. H. flanged cast semi-steel	2-in. and under, E. H. screwed pattern, all bronze 2½-in. and over, E. H. flanged semi-steel and bronze (O. S. & Y. pattern)	Compressed asbestos $\frac{1}{16}$ in. thick	E. H. F. S. Vanstone for steel pipe	Standard steel
[illegible] off [illegible]	Boiler side of blow-off, E. S. steel 2-in. and under, E. S. steel 2½-in. and over, inside station, F. S. steel; outside station, E. H. flanged cast semi-steel	Boiler side of blow-off, E. S. steel 2-in. and under, E. S. screwed cast-iron 2½-in. and over, E. H. flanged cast-iron	2-in. and under, E. H. screwed cast-iron and bronze 2½-in. and over, E. H. flanged cast-iron and bronze (O. S. & Y. pattern)	Compressed asbestos $\frac{1}{16}$ in. thick	E. H. steel for steel pipe 2-in. to 4-in., welded, 4-in. and over, Vanstone Cast integral for cast semi-steel pipe	Standard steel
[illegible]	2-in. and under, E. S. galvanized steel 2½-in. to 3-in., standard galvanized steel 4-in. and over, F. W. steel or cast-iron	1½-in. and under, standard screwed cast-iron 4-in. and over, standard flanged cast-iron	2-in. and under, standard screwed composition (inside screw pattern) 2½-in. to 3½-in., standard screwed, cast-iron and bronze 4-in. and over, standard flanged cast-iron and bronze (O. S. & Y. pattern)	Packing "Rainbow" $\frac{1}{16}$ in. thick	Standard cast-iron threaded for wrought-iron or steel pipe Cast integral for cast-iron pipe	Standard steel
[illegible] pressure	2-in. and under, E. S. steel 2½-in. to 12-in., standard steel 14-in. to 22-in. O. D., steel $\frac{5}{16}$-in. thick 24-in. and over, standard cast-iron, for horizontal runs, O. D. steel, $\frac{5}{16}$-in. thick for vertical runs	3½-in. and under, standard screwed cast-iron 4-in. and over, standard flanged cast-iron	2-in. and under, standard screwed composition (inside screw pattern) 2½-in. to 3½-in., standard screwed cast-iron and bronze 4-in. and over, standard flanged cast-iron and bronze (O. S. & Y. pattern)	Packing "Rainbow" $\frac{1}{16}$ in. thick	12-in. and under, standard cast-iron 14-in. to 22-in., standard Vanstone 24-in. and over, cast integral	Standard steel In large flanges bolts ⅛ in. smaller than standard
[illegible]	12-in. and under, standard steel 14-in. to 22-in. O. D., steel $\frac{5}{16}$-in. thick 24-in. and over, standard cast-iron and vertical spiral riveted galvanized steel	Standard flanged cast-iron	Relief valves, cast-iron and bronze Water-sealed 18-in. and over, with hydraulic cylinders and remote control	Packing "Rainbow" $\frac{1}{16}$ in. thick	12-in. and under, standard cast-iron 14-in. to 22-in., standard Vanstone 24-in. and over, cast integral Vertical spiral riveted, standard cast-iron	Standard steel In large flanges bolts ⅛ in. smaller than standard
	2-in. and under, E. S. steel 2½-in. and over, standard steel	3½-in. and under, standard screwed cast-iron	2½-in. and under, standard screwed composition 4-in. and over, standard flanged cast-iron and brass (inside screw pattern)	Compressed asbestos	2-in. to 4-in., F. S. welded	Standard steel

* [illegible] strong, E. H., extra heavy; F. S., forged steel; C. S., cast steel; I. P. S., iron-pipe size; F. W., full weight; O. D., outside diameter; O. S. & Y., outside screw and yoke. Unions to be "Edwards." All semi-steel material to be tested to 600 pounds. All valves provided with removable seats and disks.

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ELECTRICAL FEATURES

Voltage. For large power-plant work, the usual voltage for the generators is either 6600 or 11,000, there being a tendency toward the higher voltage in modern work. This, and the outgoing transmission voltage, will, in the majority of cases, be governed by existing conditions and local policy. Sixty cycles is almost universal in this country, except for railway work where 25 cycles is the generally adopted frequency. There are a few installations of 40 cycles and 50 cycles; 50 cycles is, however, quite general in Europe. From all points of view, 50 cycles would probably be the best frequency to use for general work, as the synchronous speed variation possible with it is greater than with 25 cycles, and the inductance and reactance are proportionately less than with 60 cycles. However, the use of 60 cycles in this country has become so general that it is practically out of the question to consider any departure from it except for railway work as mentioned above. The frequency used in any particular locality will, of course, be governed by local policy in the same way as voltage.

For power work in the station, 440 volts is the best from all points of view. In some installations there will be a few large motors of 100 horse-power or more, for which a 2300-volt bus should be provided. Whether or not such a bus will be necessary is, of course, dependent upon the number of large motors involved in the station design. For general lighting, a 110-220 volt, three-wire system should be used and motors of one horse-power or less can be connected across the 220-volt wires. Particular attention should be given to protection of the station bus against outside disturbances. As mentioned in connection with the heat balance system, the provision of a house generating unit paralleled either directly or through a motor-generator set on the main bus, and provided with protective devices so that system disturbances cannot be communicated to the house generator, is believed to be the best arrangement for the supply of power for use within the station. Nothing should be placed on the exciter bus aside from the exciting connections. In some

stations the emergency lighting system is fed from the exciter bus, but even this is believed to be bad practice.

The lighting of a power-station should be carefully worked out. For general illumination in the turbine room, four to five foot-candles will give a suitable illumination. For the switchboard room considerably more than this is usually necessary but attention should be given more particularly to the distribution of the lighting in the switchboard room than to the intensity of it. Direct illumination on the instruments and operating panels so arranged as to be free of reflections from the instrument faces is what is necessary and a great deal of light in other parts of the room is not of any particular use.

In the boiler room and at other points where machinery is located, no quantity can be given for the illumination per square foot. This is a matter of local lighting entirely and is best accomplished by laying out the lighting units on the job after the station is sufficiently completed so that the necessity for lighting in particular places can be seen. In arranging the illumination of a power-station, the painting and reflecting characteristics of the surrounding objects should always be considered. Good lighting should always be localized at points where the work of operation is conducted.

Bus System. The bus arrangement adopted must be governed largely by the type of feeder system the station is to supply. If there are a great many outgoing feeders at station voltage (and by this is meant generator voltage) a system of separate phases is often desirable. This system consists in dividing the switch house into three longitudinal sections and placing the "A" phase in one, the "B" in another and the "C" in the third section. If the station is designed to feed an outdoor switching station, such an arrangement might not have any particular advantages and an ordinary bus structure carrying the three phases in a group is, in general, perfectly satisfactory and probably less expensive.

In stations where there are a great many oil switches and in which there is likely to be a good deal of work being done on switch mechanisms, it is often advisable to place these mechanisms on a separate floor above the switch floor. Whether or not this

shall be done must be governed by structural and other conditions of the particular work in hand.

Control. The control board which carries the means for operating the switching apparatus should be a benchboard, as this type of board is much easier to manipulate, and is from all points of view superior to the old type of vertical switchboard. The feeder controls may be on bench or vertical boards depending upon the amount of manipulation that is likely to be necessary. Instrument boards may be placed directly behind the benchboard and it is well to allow a space between the benchboard and the instrument board, so that instruments may be worked upon without having to lean over the benchboard, thus perhaps opening or closing switches accidentally.

Transformers may be placed inside or outside the station, depending on available space and other local conditions. There are no rules to sèrve as the basis for a choice. For very high voltage an outdoor switching station is usually the best. It is less expensive to construct and safer from an operating standpoint, but in all these matters the local conditions and policy will govern, as there are no general principles or rules which can be laid down to govern the choice.

DISCUSSION

Mr. F. M. Van Deventer:* Mr. Clarke has given in his paper in an interesting manner a general consideration of the economic problems incidental to the design of central power stations. It is to be regretted, however, that he has not given in more detail the methods of arrival at his conclusions, as other designers would benefit by such sample analyses in the solution of their problems but cannot do so from abstract conclusions without knowing the controlling conditions.

This discussion is intended to serve two purposes:

1. To open a consideration of several of the technical points involved in the selection of equipment.

2. To present detailed analyses of three problems touched upon by Mr. Clarke, one of which leads to a conclusion quite different from that which he quotes.

Natural-Draft Stack vs. Induced-Draft Fan. While Mr. Clarke does not openly express himself as preferring natural draft, the fact that he gives data on stack design and mentions fans only as a necessary evil involved in economizer installations, leads to the assumption that he does not recommend induced-draft fans for boiler installations without economizers.

For the purpose of comparison, an example is taken of four 2088-horse-power boilers without economizers, connected by suitable outdoor breeching to a central stack supported on the building steel and foundations. The cost of such an installation is about as follows:

Cost of steel stack with nine-inch brick lining, including double wall, insulated outdoor breeching and cost of erection,	$60,000
Extra cost of building steel and foundation, breeching inside of building, etc.	30,000
Total installation cost	$90,000

*Engineer, National Tube Co., Pittsburgh.

The fixed annual charges at 15 per cent. would be $13,500. The characteristics of a stack 21 feet in diameter by 325 feet high with gas temperature ranging from 450 degrees at 100 per cent. boiler rating to 550 degrees at 300 per cent. boiler rating, are indicated in Fig. 2. This stack serves four 2088-horse-power boilers with 20-foot tubes, each boiler being 51 tubes wide and 18 tubes high. The theoretical draft is indicated by curve *A* which depends upon the temperature of the gases and ranges from 1.75 inches at 100 per cent. rating to 2.1 inches at 300 per cent. rating. The net draft available at the stack opening is less

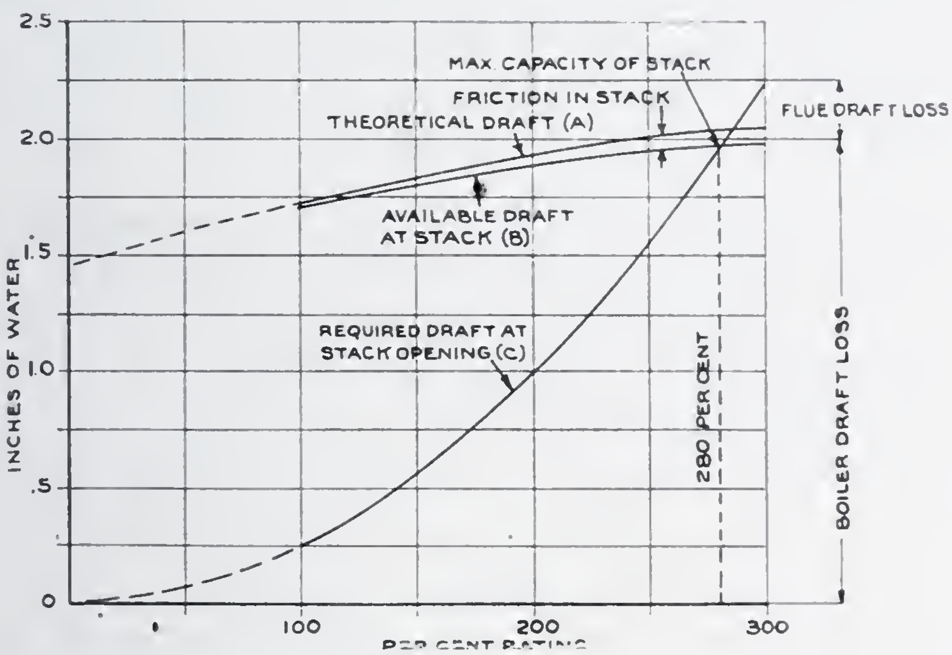

Fig. 2. Characteristics of Stack.

than the theoretical draft by an amount as indicated for friction in the stack. Curve *B* then represents the net draft available at the stack opening. The boiler draft loss is taken as two inches at 300 per cent. rating and the flue draft loss as ¼ inch at the same rating. This gives one point from which the parabola is constructed, representing the required draft at the stack opening for any rating (curve *C*). The difference between available draft and required draft at low ratings—that is, the difference between curves *B* and *C*—is taken up by the dampers. The maximum capacity which can be carried by the stack under the conditions assumed is determined by the point of intersection of

curves *B* and *C*; where the dampers are wide open and all the available draft is used. This is seen to be at 280 per cent. of the boiler rating. Of course, if the uptake temperature were higher than 550 degrees, the available draft and the capacity of the stack would be slightly increased.

If induced-draft fans were used, each boiler would have an individual fan. The size selected for comparison has a maximum capacity of 240,000 cubic feet per minute at five inches static pressure and 575 degrees F., and the cost per unit, for fan and drive, is $10,000. The cost of erection is $1500, and cost of duct and stub stack, $3000. The total cost per unit is $14,500, and the total cost for four units, $58,000. The annual fixed charges at 15 per cent. equal $8700. The cost of fuel for drive (at normal boiler rating) is $4500, and the cost of attendance $1800. Then the total annual charge is $15,000, which is seen to be about $2000 more than the annual charge against the stack. There is the advantage, however, that the fan has sufficient capacity to operate the boiler at 400 per cent. of rating. If the normal operating rate is 250 per cent. of rating, we have available 60 per cent. additional capacity for peak-loads with the same number of boilers in operation. With the stack used in this comparison, only 20 per cent. excess capacity is available for peak-loads, unless the forced draft is increased to such a point that the forced-draft fan would assume a part of the draft loss in the boiler. The resulting positive pressure in the furnace would be so destructive to the setting, doors, etc., that such operation could not be continued. Thus the natural-draft stack does not fit conditions where high peak-loads must be picked up on short notice since, if stacks are used, extra boilers must be carried along at low ratings, ready to take the peak-loads. In the case of installations where the load may be carried fairly constant, or where the capacity of the boiler is limited by the stoker capacity, the latter objection fails; but in such cases induced-draft fans could be installed with a maximum capacity which need not be greater than the capacity of the proposed stack. Such a fan installation, including the items enumerated above, would involve annual fixed charges of only $10,860, which is nearly $4000 less than those for the stack. It would be interesting to know

how Mr. Clarke justifies the use of natural-draft stacks on such installations.

In connection with the graphic analysis of stack capacity as here presented, it is well to point out the fallacy of the so-called "horse-power formulæ" as given in many mechanical hand-books. Most of these formulæ give the horse-power in terms of diameter and height of stack without regard to the gas temperature. With such a formula it would seem possible to obtain almost any horse-power from a short stack simply by making the diameter large enough. Now, it is quite obvious that a short stack will not pull gases at high ratings through a boiler and economizer, which have high draft loss, because the theoretical draft available with cool gases would be low; hence the use of such formulæ is inadvisable, and the graphic analysis is recommended for such problems.

Economizers. Mr. Clarke states that the installation of an economizer with fuel costs at their present level is of doubtful advantage, since when costs of increased building, economizer, induced-draft fans, piping, maintenance, and operation are considered, it will usually be found that an increase in the height of the boiler will result in a greater operating efficiency, considered financially, than if economizers are used. His curves showing the comparative efficiencies of a 15-high boiler and 64 per cent. economizer, versus a 20-high boiler without economizer, do not seem consistent. He shows, at capacities from 2250 to 3250 boiler horse-power, a higher efficiency for the boiler alone than for the combined unit. Since the combined unit has 23 per cent. more surface than the high boiler alone and since the thermal head affecting heat transmission is greater in the combined unit, it does not seem possible that the efficiency of the high boiler could be higher than that of the combined unit.

Fig. 3 shows a comparison between a 20-high boiler with no economizer and a 15-high boiler with 60 per cent. economizer. Curve *A* shows the temperature of the gases leaving the high boiler. Note that although the gases are cooled to within 50 degrees of the steam temperature at the low rate of evaporation (100,000 pounds from and at 212 degrees) it is impossible to

cool them below steam temperature, no matter how much heating surface is added. Curve *B* shows the relatively high temperature of the gases leaving the shallow boiler, and curve *C* shows the temperature of the same gases after traversing the economizer. On account of the fact that the temperature of the water in the economizer tubes is below that of the steam and water in the

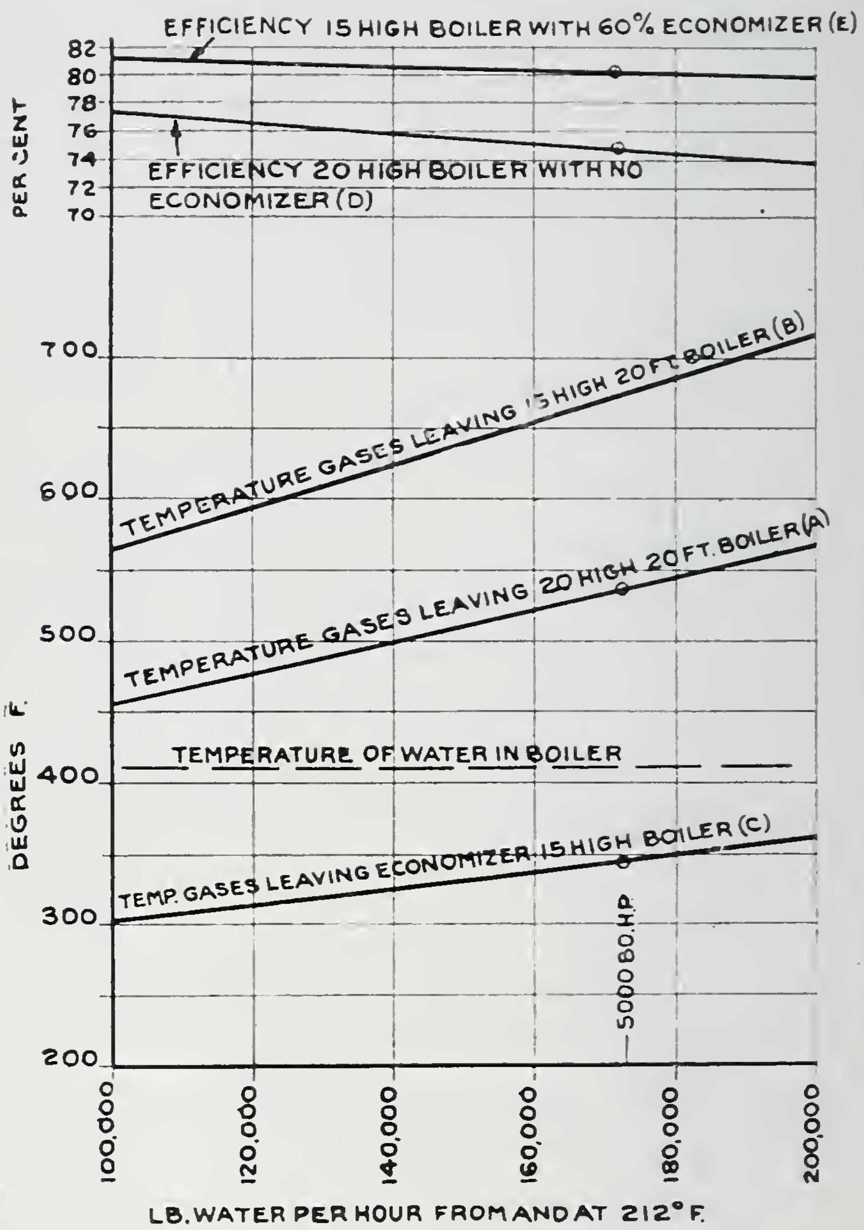

Fig. 3. Comparison of Boiler and Boiler-Economizer Unit.

boiler tubes, a given amount of heating surface in economizer tubes is more effective in transferring heat than the same amount of boiler-tube surface, due to the greater temperature difference. It is also possible to extract heat from the gases below steam temperature, so the loss due to sensible heat carried away in the gases is much less than in the case of hotter escaping gases, and

the heat thus saved from the stack goes into steam, thereby increasing the efficiency. Curves D and E show the efficiencies corresponding to the two types of units. Note that when developing 5000 horse-power the efficiency of the high boiler is 75 per cent. and of the combined unit 80.5 per cent.

The superiority of the economizer unit is not proved by citing higher thermal efficiency alone. In many problems the first cost and operating charges against equipment designed to increase thermal efficiency, are so high that the saving costs more than it is worth, and the result is a lower "economic efficiency."

Table II is an economic comparison of the two types of steam generating units, based on a single unit. The tabulation is self explanatory and shows a net saving of $10,835 per year *per boiler unit.*

One frequent criticism of economizers is that more power is required for the induced-draft fans on account of the higher draft loss, which eats up much of the saving effected by the economizer. This fact is not so important as it sounds at the outset, because less power is required to move a given *weight* of cool gases than for the same weight of hot gases. For example, to handle gases at 340 degrees F. (800 degrees absolute) requires only 0.80 as much power as at 540 degrees F. (1000 degrees absolute), so if the economizer increased the pressure against which the induced-draft fan operates by only 25 per cent. $(\frac{1}{0.80} - 1 = 0.25)$, then the economizer set-up would require no more power than the boiler alone.

Since the results of this comparison of high boiler vs. shallow boiler and economizer are so radically different from Mr. Clarke's data, it is hoped that he will give a complete explanation of his efficiency curves. If he will explain by heat balance what becomes of the additional heat that the combined unit *must* extract from the gases on account of more total surface and greater thermal head, the logic of his efficiency curves might become clearer.

Steam Piping. Mr. Clarke recommends that high-pressure steam piping be designed for velocities below 10,000 feet per

TABLE II. ECONOMIC COMPARISON OF BOILER AND BOILER-ECONOMIZER UNIT

	Boiler alone	Boiler with economizer	
Boiler	20-high, 20-foot tubes	15-high, 20-foot tubes	
Heating surface, boiler only	20,000 square feet	15,000 square feet	
Heating surface economizer	None	9,000	
Total heating surface	20,000	24,000	
Steam pressure	275 pounds gage	275 pounds gage	
Superheat	150 degrees	150 degrees	
Overall efficiency 5000 boiler horse-power developed	75 per cent.	80.5 per cent.	
Cost of fuel per year*	$193,000	$180,000	
Difference			$13,000
Cost of boiler	$ 66,000	$ 52,500	
Cost of economizer		18,000	
Extra cost of building		2,000	
Total cost of unit	$ 66,000	$ 72,500	
Difference			$ 6,500
Interest on extra investment, 15 per cent		$ 975	
Extra power for induced draft		590	
Additional attendance		600	
Extra fixed charges with economizer		$ 2,165	
Net annual saving with economizer $13,000-$2,165			$10,835

*6000 hours, 13,000 B.t.u. coal, $3.75 per net ton, 5000 horse-power developed.

minute, and states that the pressure drop method of design is not satisfactory.

The method recommended by the writer goes one step further than the pressure drop method and carries the analysis through to a financial comparison. This method has been used successfully on both simple and complicated piping systems. Fig.

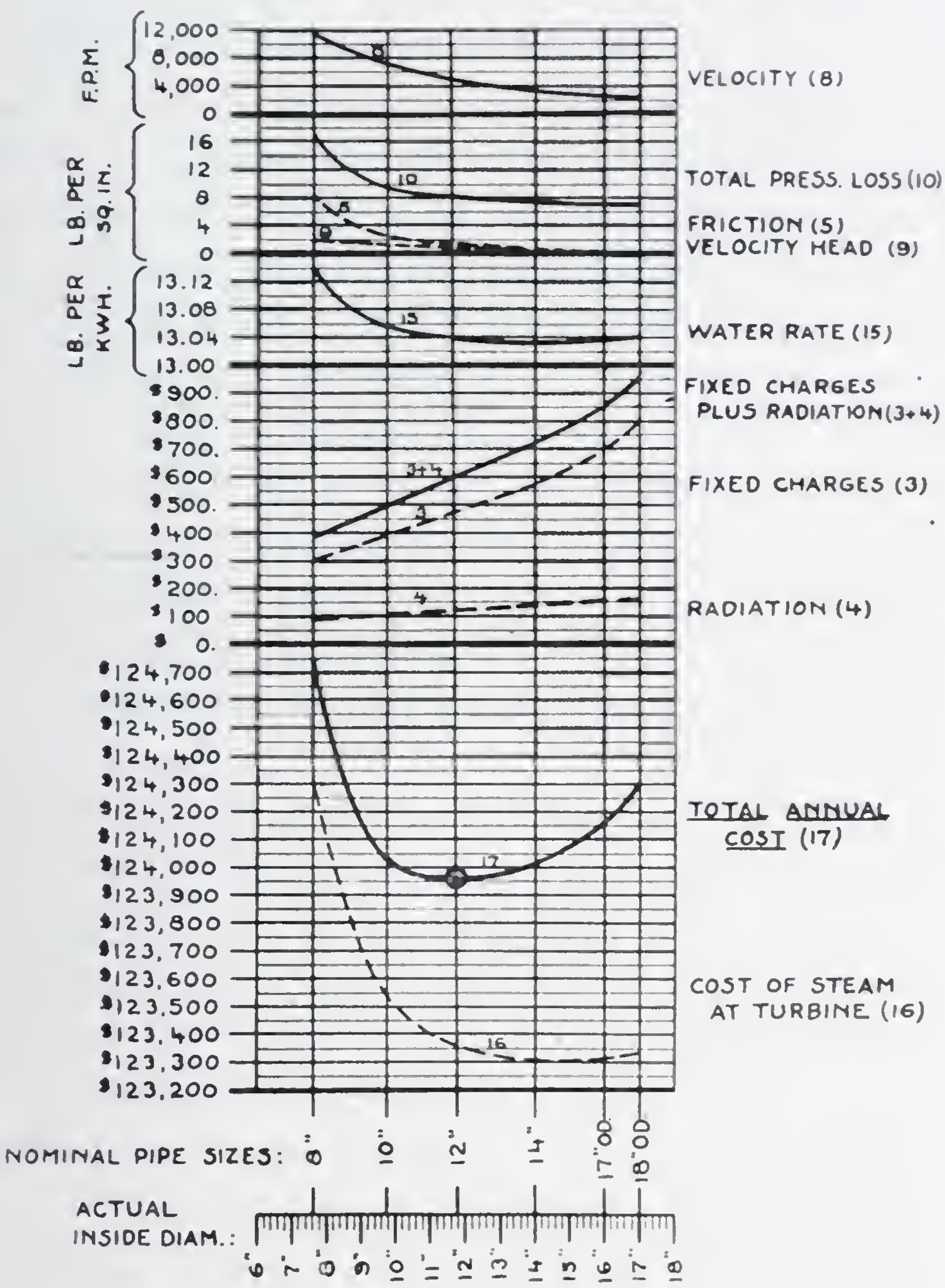

Fig. 4. Analysis of Steam-Header System.

4 shows in graphic form the method of analysis of a steam-header system to determine the financially economical size. This analysis considers all of the variables which affect the fixed or operating charges. The installation used for this analysis is an actual one which was recently made, and embodies a 10,000-

kilowatt turbine and two 1500-horse-power boilers. The steam header consists mostly of a straight run of pipe having only long radius bends, so that it was a simple matter to calculate the friction loss, and the velocity is uniform throughout the length of the header. It was not necessary to consider future extensions, as the plant was located in cramped quarters between mill buildings and the pressure was higher than that of the mill system, and hence the two systems could not be interconnected.

The designer would know at the outset that the economical size would probably be between 10 and 14 inches, but the graphic analysis will be applied to six sizes, from the ridiculously small to the ridiculously large header, in order to bring out the effects. Fig. 4 shows the conditions for 8-, 10-, 12-, and 14-inch nominal, and 17- and 18-inch outside diameter all extra strong. Curve *5* shows the total friction loss in the header system. Curve *9* represents the velocity head of the steam in the header. Curve *10* is the sum of curves *5* and *9*, plus the pressure loss from the saturated steam drum to the header, and represents the total pressure loss from the saturated steam drum to the turbine throttle. Curve *15* shows the water rate of the turbine corresponding to the pressure which remains after the total pressure loss *10* has been deducted from the pressure at the saturated drum. Since the water rate of the turbine decreases with larger pipe, the annual cost of steam to run the turbine will also decrease with larger pipe sizes. The cost of steam at the turbine per year at an assumed load factor is indicated by curve *16* and is practically constant for sizes above 12 inch, since the pressure loss becomes negligible. However, as the pipe size is increased, the radiation loss and cost of pipe and covering will increase. This is shown by curves *4* and *3*. When these are added to curve *16*, curve *17* is obtained, which represents the total annual charges against the system, and the minimum value is found to occur with 12-inch pipe.

It is seen from this study that for the case at hand the economical pipe size corresponds to a velocity of 5000 feet per minute.

The steam-headers in most modern plants are of complicated form, containing many fittings, interconnections, etc., and at the outset it seems that a financial analysis similar to the preced-

ing one would be impossible. The writer has, however, used this method of analysis on a complicated steam-header system, serving three turbines, and a heavy outside steam load from 12 boilers. In a system of this kind, with a given steam distrbution, the velocity of flow varies at almost every fitting in the whole system. In designing for a velocity such as 10,000 feet per minute the question arises, as to whether the *stated* velocity refers to the *maximum* or to the *average* velocity. When the case mentioned was completely analyzed and the economical header size determined, it was found that the various sections of pipe in the header carried velocities from almost nothing up to 16,000 feet per minute, which applied to one short run of pipe. Now, if the size of the whole header had been selected so that the velocity in this one section had been only 10,000 feet per minute, the rest of the header would have been excessively large; thus in most cases, it is not successful to design for velocity.

If a system is to be designed for a *given pressure drop*, the question occurs as to what is the economical pressure drop. Different engineers recommend from 5 to 30 and even 50 pounds pressure drop; the latter on the erroneous assumption that, since when a pressure drop occurs the energy remains in the steam, it is still available to run a turbine. The writer believes that the method just presented—that of a complete financial analysis—is more successful than any of the other proposed methods and that, even though the pressure losses calculated may be considerably in error, the same error will occur in the calculation for all the pipe sizes considered and its effect will be annuled in the final analysis.

It is distinctly pointed out that the conclusions drawn in this discussion are not offered as criteria for all similar problems, but it is believed that the methods presented will be of some assistance to others in the analysis of the peculiar conditions of their problems.

Mr. Clarke offers three criticisms of the writer's induced-draft fan analysis. He thinks the fan mentioned is so large that its use would be impracticable in an actual installation and asks if the writer has ever seen a fan of this size. The answer to this question is that the fan used in the comparison is a Green

Fuel Economizer Company standard No. 8, RR, radial-flow double-inlet fan. There are a number of fans of this class in operation at steel-mills in this district and, as to the size being excessive, it is pointed out that the Green Fuel Economizer Company makes two sizes larger. We have some No. 8 fans in use in one of our coal-fired installations and we consider them very satisfactory. Many central-station men take the point of view which Mr. Clarke expresses, but the writer, being a steel-works man, is accustomed to the use of induced-draft fans handling large volumes of waste-heat, blast-furnace and similar gases, and does not hesitate to contemplate the use of induced-draft fans for central-station work; in fact, we use them on some coal-fired boilers, as well as on waste-heat installations.

Mr. Clarke states that the higher ratings available with fans do not constitute an advantage in the case of the Colfax plant, since the stokers limit the capacity at which the boilers can be operated to 275 per cent. of rating, and that, since the stack has sufficient capacity to serve the stokers at their maximum capacity, any additional induced-draft equipment would be of no avail. It is for this reason exactly that the second comparison was given in the writer's discussion; namely, a comparison between the stack "as is" and a fan having the same maximum characteristics as the stack. This comparison shows a saving of $4000 per year per boiler unit in favor of the fan. What has the stoker to do with this?

Also, where double-stokered settings are used, the coal-burning capacity is not limited to such low ratings and, in the case of boilers fired by blast-furnace gas, high combustion rates may be reached, so that Mr. Clarke's contention that the additional capacity of the large fan over that of the stack is not an advantage, does not fit all cases. It was the writer's intention to give a broad treatment of the subject so that other designers can apply the method of analysis to their peculiar conditions and determine for themselves whether stacks or fans are preferable.

Mr. Clarke's criticism that the writer's figures are unreliable, as some items (such as cost of stub-stack which is used with fan) were omitted, is unfounded. The costs used for the fan installation are based upon the actual costs of a recently constructed plant.

In criticizing the writer's discussion on economizers, Mr. Clarke did not make any attempt to explain his efficiency curves, wherein lies the whole difference of opinion between us. If he would explain how such curves are possible, the argument would probably be settled, but since a much lower up-take temperature obtains, the dry gas loss, loss from moisture in coal, loss from moisture in air, and loss from moisture by burning hydrogen, must be smaller in the economizer installation. There is no reason why the CO loss or carbon in the ash loss should be greater with the economizer, and the radiation loss should not be any higher in the case where a lower boiler is used with the economizer, if the economizer and connecting flue are properly insulated. Where then does the heat show up in the heat balance, which obtains from the further cooling of the gases, unless it is in increased efficiency?

Mr. Clarke criticizes the item of $2000 which is added for increased building cost with economizers, and says that if it were $20,000 the item would look more reasonable. Apparently he has overlooked the fact that the tabulation is based upon one boiler or boiler and economizer unit. In the case of a 10-boiler plant this item would be $20,000, which accords with his criticism. It should be pointed out that the type of economizer contemplated in this comparison is neither the cast-iron tube type nor the ordinary boiler-section steel-tube, but is of the type of construction extensively used for superheater tubes consisting of a two-inch steel tube upon which are forced corrugated cast-iron rings. With this type of construction, an area of about seven square feet of gas side surface is obtained per square foot of water side surface, and, as the gas side surface is the determining factor in heat transfer, this type of construction results in an economizer of low first cost, low maintenance, and a great saving in space required, the latter being another reason why $2000 is a conservative figure for increased building cost.

Mr. Clarke criticizes the writer's method of analyzing steam-header design problems on the ground that too much time is required for such analysis and that an experienced man can select sizes more satisfactorily from his experience than by calculation. He points out that in the case of Colfax the plant was to be

completed in one year and consequently such problems could not be attacked in detail. In answer to the latter criticism it is pointed out that the plant which the writer mentioned where the analysis of a complicated steam-header system was successfully made, was the power-plant for the proposed United States gun plant for Neville Island and that this power-plant was to have been completed in nine months, which is three months shorter than the time allowed for Colfax, yet it was found to be advantageous to make such an analysis. In the example illustrated by Fig. 4 the difference in annual cost between say a 10-inch and a 12-inch header would be $500, so that if a designer's time for one week is required for making such an analysis, the investment for his time would be saved in a few months. Further, if an uneconomical pipe size is installed, the loss will continue indefinitely, and is uncontrollable. On the other hand, a station heat balance is flexible, since means are usually provided for varying the amount of exhaust steam available for feed-water heating. Since Mr. Clarke makes a very searching and exhaustive study of station heat balance, his contention that a theoretical analysis of steam-pipe size is unwarranted, does not seem consistent with his practice.

As to the criticism that an experienced designer can determine pipe size without calculation, not all engineers who are concerned with such problems are satisfied until a theoretical analysis has been made, and it is for their benefit that the writer's method was offered. The fact that a number of engineers (central-station as well as steel-works men) have been interested in this form of analysis is sufficient justification for its publication.

MR. D. D. PENDLETON:* When the speaker entered the economizer field many boiler-plant designers did not consider economizers worth while, admitting, however, that a comparison of anticipated heat balance with and without economizers would easily justify the use of economizers. They contended, with plenty of evidence to back them, that in actual performance

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losses by radiation and particularly by air infiltration cut down the margin of profit on investment sometimes to an actual loss.

The economizer proposition boils down to the problem of obtaining, in actual operation, the conditions on which the design of the economizer is based. If this can be done there can be no argument on this matter when taking into consideration the added advantages of the steel-tube economizer with "Foster" extended surface in reducing space requirements, building costs, etc.

By washing down with water we greatly reduce operating and maintenance cost and at the same time obtain better cleaning; therefore, other conditions being equal, greater work is done per square foot. The compactness of this design makes it possible to locate nearer the boiler in all cases. This reduces losses and any initial waste on account of long flues. A small casing and a short flue can be made for all practical purposes absolutely gas tight. This makes it possible to increase suction to produce high gas velocities, thus increasing the rates of transfer and increasing the work done per unit of heating surface.

The mere bulkiness of other economizers, the openings for chains to operate scrapers, and the necessity for by-pass damper, all contribute to increase losses by radiation and air infiltration. The impossibility of eliminating air infiltration also makes it out of the question to increase the transfer rates by increasing gas velocities. The necessary increase of suction pressure would make air infiltration losses prohibitive.

The speaker does not quite understand Mr. Clarke's Fig. 1. The mere statement of 64 per cent. economizer surface means very little. The work done depends upon gas velocity, radiation losses, air infiltration, and amount of surface. We have no hesitancy in saying that the combined efficiency of a 13-high boiler with a "Foster" economizer, having 100 degrees rise at ordinary normal loads, will be from five to seven per cent. greater than the efficiency of a 20-high boiler without economizer at the same output. This is shown in Fig. 5, showing the performance of a 13-high boiler with a 78 per cent. economizer in one case, and with 53 per cent. economizer in another case, as compared with a 20-high boiler without economizer.

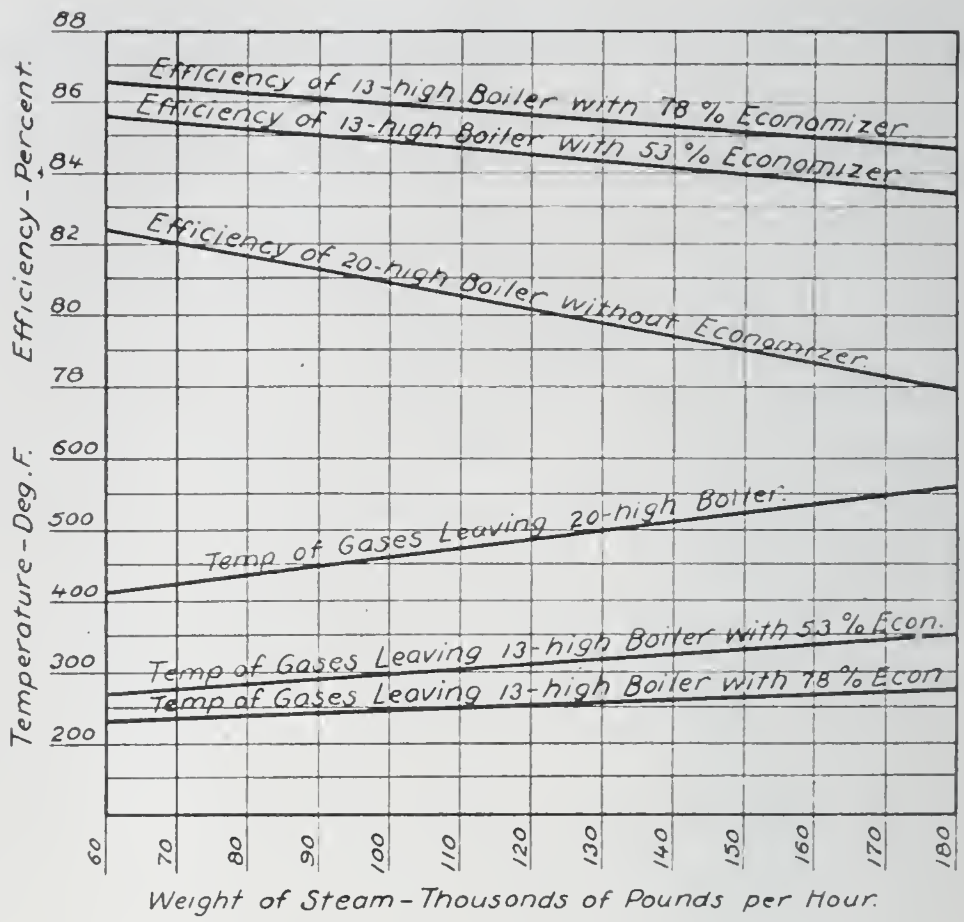

Fig. 5. Effect of Economizer.

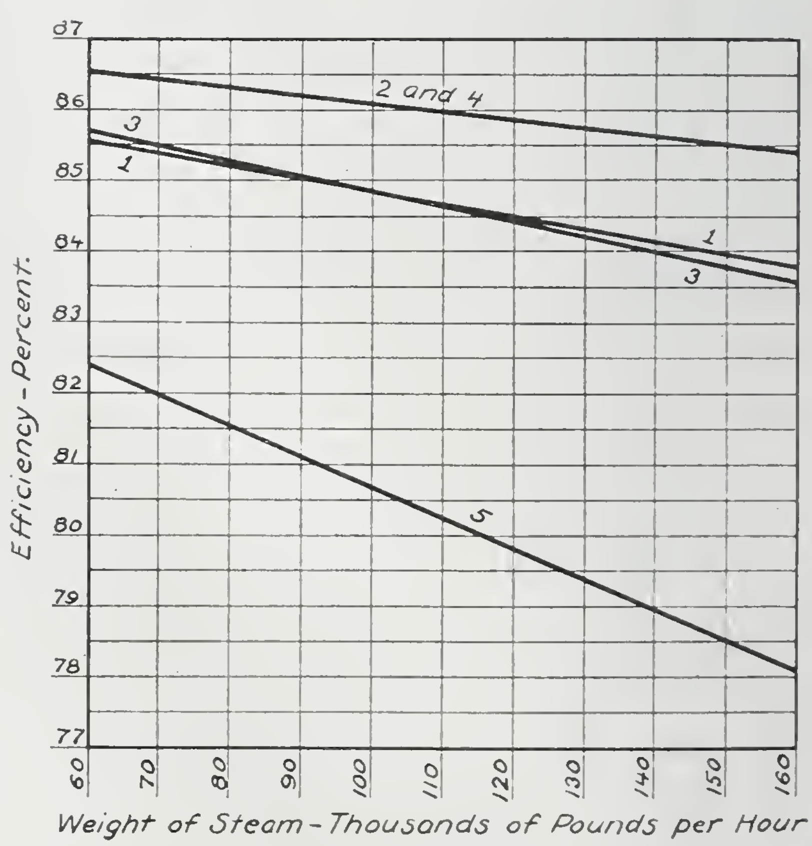

Fig. 6. Comparison of Various Arrangements of Boiler and Economizer.

Fig. 6 shows efficiencies of a 20-high boiler and a 13-high boiler with different economizer units, as follows:

1. 12,728 square feet; 13-high boiler with economizer, 6720 square feet.
2. 12,728 square feet; 13-high boiler with economizer, 10,080 square feet.
3. 18,900 square feet; 20-high boiler with economizer, 5020 square feet.
4. 18,900 square feet; 20-high boiler with economizer, 8400 square feet.
5. 18,900 square feet; 20-high boiler without economizer, feed-water, 200 degrees.

Curve *5* shows the efficiency of a 20-high boiler with no economizer. Curve *3* shows the efficiency of the same boiler with 26.6 per cent. economizer added. Curve *4* shows the efficiency of the same boiler with 44.4 per cent. economizer added. Curve *1* shows the efficiency of a 13-high boiler with 53 per cent. economizer added. Curve *2* shows the efficiency of the same boiler with 78 per cent. economizer added.

This proves conclusively that the 20-high boiler without economizer is by far the least efficient of any of the combinations shown.

Curves *2* and *4*, being identical, show that the same economy at the same load can be obtained from 22,808 square feet of total surface, when arranged as a 13-high boiler and 80 per cent. economizer, as from 27,300 square feet arranged as a 20-high boiler and 44 per cent. economizer—a saving of 4492 square feet of surface, which indicates that economizer surface is a much better investment than equivalent boiler surface.

The speaker believes that Mr. Van Deventer is absolutely on the right track, and that the time is coming when economizers will be installed for the maximum rise possible without generating steam, and the boiler rating will be run up as required or the amount of surface in the boiler reduced so as to produce gas temperatures leaving the boiler high enough to give the best overall results.

Mr. G. G. Bell:* Mr. Clarke has presented a very comprehensive statement of the factors affecting the type, equipment, and selection of site of modern large central stations. Changes in the art have entailed considerable difference in the designs to meet differences in conditions and load; moreover, differences of opinion exist among designers.

Great progress has been made in the art of transmission. With high voltages the liability of interruption from electrical storms has been much reduced.

The Windsor power-station was put into operation in the fall of 1917. Most of the power from this station is delivered to the Washington, Pa., substation of the West Penn Power Company, about 29 miles distant; to the Canton substation of the Ohio Power Company; and to the Akron substation of the Northern Ohio Traction & Light Company—the latter being about 80 miles from the Windsor power-station. The interruptions to the service of these stations have not exceeded one per year, and have been in the nature of switching troubles only; so, from the experience of this station, the power-house should be located at the point at which power can be generated and delivered to the customer the most cheaply, rather than with regard to the effect which long-distance transmission has on the service to the customer. This is also borne out by the performance of Pacific coast systems.

At present, the minimum freight rate on coal in the Pittsburgh district averages about 85 cents a ton and would vary up to $1.15, in order to get competition from a number of mines capable of supplying a large power-station. Allowing for transmission losses, the freight rate amounts to roughly 1/10 cent per kilowatt-hour, and is about equal to the cost of transmitting 100,000 kilowatts 50 miles over a double circuit, 132,000-volt tower line. These figures include the step-down substation to step down to 25,000 volts, but do not include the step-up substation. This distance will, in general, exceed the maximum distance that coal to generate this amount of power can be hauled for the minimum freight rate. A closer study would probably indicate that the economical distance to transmit power was somewhat in excess of 50 miles.

*Manager Power Development, West Penn Power Co., Pittsburgh.

One additional factor of great weight in favor of a mine-mouth power-plant is the certainty of fuel supply in times when the railroads are heavily loaded and cars are scarce or there is labor trouble on the railroads. It is then of vital importance to be able to transmit energy instead of shipping coal. There is also the assurance that the power-house will then get one grade of coal—which otherwise is not the case, at times when cars are scarce, as it will have to go into the market to get the excess needed over what it can get on its contracts. This necessity forces the station to pay a high price for the extra coal at the time it is most difficult to get.

Mr. Clarke mentions the difficulty of obtaining suitable sites for large power-stations at the mine mouth. This is due to a great extent to the demand for coal lying along the river; first, on account of the easy rail connections which can usually be had at such locations, and second, on account of the advantage of river transportation, which enables the various steel-mills and manufacturing concerns located along the river to get their coal delivered at a lower price. These two factors have greatly increased the value of coal lying adjacent to the rivers which are large enough to supply the necessary circulating water for a large power-house.

In addition to the saving in freight rate by having the power-station located at the mine mouth, there is the saving at the mine of handling the loaded cars, due to the care which is frequently taken in topping the railroad cars so as to get full capacity, especially at times when coal cars are scarce. At the power-station there is the saving in switching and unloading. This is of particular importance where the haul is so long that in the winter the coal cars become frozen. This greatly increases the expense and difficulty of unloading coal.

A place for ash disposal is very important. This is particularly so where low-grade fuels are burned, as the rates charged by the railroads for disposing of ashes are very high. In the Pittsburgh district it is not especially difficult to get land for ash disposal, as the numerous valleys between the hills furnish ideal dumpage for large quantities of ashes.

An item of some importance in selecting a power-station

site is proximity to a labor market of sufficient size to take care of the demands of the power-station, and of towns to furnish the necessary residence facilities for the employees. The building of villages represents an investment of a fair percentage of the power-house cost, especially when the installed capacity is small, and sufficient rental is seldom secured; consequently, the cost of maintaining and carrying the houses results in a loss.

Rivers in the Pittsburgh district are subject to very severe rises during the flood season. The Allegheny River at the site of the Springdale and Colfax stations has a maximum flood rise of about 32 feet. At the Windsor plant, near Wheeling, the Ohio River has a rise of 52 feet, and at Cincinnati the maximum flood stage is 72 feet above low water. Taking care of this exceptional water rise is a large item in the first cost of the plant and adds considerably to the time of construction. As the chief effect of these high floods is the uplift on the turbine-room basement floor, it is advisable to keep the turbine room as narrow as possible.

Mr. Clarke recommends that at least 12 hours' ash storage be provided. A capacity of 24 hours' storage is little enough, and more is advisable if it can be secured at reasonable cost. Breakdowns in the transportation system, labor trouble, and inability to get men to work at times when high loads are being carried on the plant—which might necessitate the removal of ashes at night—all require increased storage. If ashes have to be removed at regular intervals, say once a shift, it requires a high state of organization, and any emergency may necessitate a shut-down of a section of the boiler room or increased maintenance due to stoker burn-outs. In one plant in which boilers are run at about 250 per cent. maximum rating when the plant is putting out about 90 per cent. of the maximum turbine capacity, men will not work in the ash basement because of the gases discharged through the ash-pit doors. In addition, these gases are very destructive to steelwork, necessitating the entire renewal of all steelwork in the ash basement and the doors inside of a period of three years from the time the plant was put into operation.

Where a clinker grinder is installed, there are more openings from the ash-pit into the ash-pit basement than usual. For this reason the ash-pit should be enclosed in a pressure chamber.

allowing a certain amount of air from the air duct to be discharged into it, and the fresh air leakage from this pressure chamber only to flow into the ash basement. This will eliminate the discharge of gas into the basement. With clinker grinders as installed at Colfax and Springdale, large quantities of water are sprayed on the clinker before it reaches the grinder. This helps to reduce the amount of gas in the ash-pit but increases the problem of the disposal of this relatively large quantity of water. Where such large quantities of water are used, the air needed in excess of that furnished by the generators should not be drawn through the ash-pit basement, or in cold weather ice will form on the railway tracks, derailing the ash cars; and, in case a boiler is banked and the water is allowed to run into the pits any length of time, the doors are very apt to become frozen. Incidentally, any pockets in the blow-off piping or other water piping in the basement are apt to freeze up, especially at times of very low load such as occur on Sunday mornings, when the demand for water may be particularly low. With the use of ash-hopper doors, the water dropping on foggy mornings will cause vapor so thick in the ash-pit basement that it will be impossible for a man to see and very dangerous for him to work. Also, provision must be made in the ash basement for gutters for the disposal of the water.

The labor required to handle ashes with the submerged system is small—a 1.5-yard grab-bucket crane handling the ashes from 10,000 kilowatt capacity per hour.

With regard to the location of the switch structure, one thing to be considered in the location is the cost of foundations. Mr. Clarke states that it can be put where convenient. Where foundations are expensive, the switch structure may be placed on top of the turbine room. This has the advantage of keeping the switchboard operators away from the noise of the turbine room, and sufficiently far away so that in case of the breakage of a steam-pipe or an accident to any of the smaller machines there is very little danger of injury to the control room.

Mr. Clarke states that machine-shops, storehouse, wash-room and toilets may be placed under the boiler-room floor. This is especially the case where aisle provision is made for pulling the boiler tubes toward the outside of the building or where there are

three bunkers, as this will provide room for a fair sized machine shop on the outside of the boiler room with natural light. In plants where make-up water is evaporated, tube renewals are few; and it will not greatly disturb the boiler-room operators to have occasional tubes pulled into any aisle. It is advisable to have the machine-shop located as far as possible from the turbine room, in order to reduce the vibration. Good ventilation is required in the wash-rooms, toilets and locker rooms; and this will be provided if they are placed where some of the air for the boilers may be drawn through them.

With regard to the supply of air for the boilers, probably nine months out of the year the discharged air from the generators can be used by the boilers and is about sufficient to supply the air for one-half the boilers; that is, those on one side of the room. The air for those on the other side must be drawn from the outside. During the remaining three colder months of the year it is not advisable to move large quantities of cold air through the turbine room, on account of lowering of turbine room temperature and the resulting increased possibilities of condensation. The problem of recirculating the air for generators also calls for consideration, particularly in plants where the generators are operated at 11,000 volts or higher and there is any considerabe amount of soot in the air, as the modern air washer is not very efficient in removing soot. If the heat is to be absorbed with this arrangement, the turbine condensate must be used to cool the air. This arrangement has the additional advantage that in case of a fire in the generator, there is only a small quantity of air to support combustion in the circuit. This method of cooling the air requires that practically the entire quantity of air for the boilers be drawn from the outside.

Regarding the installation of economizers, a recent investigation of a plant in which economizers fed with water at 100 to 120 degrees F. are installed, indicated that an increase in excess of two per cent. in the economy of the station and the capacity of the boiler room, and five per cent. in generator capacity, could be obtained by installing a house generator and heating the feed water to 210 degrees. This would be a handsome return on the necessary investment, and in addition would give a more reliable

source of power for motor-driven auxiliaries. As these investigations were conducted for a plant which was designed for economizers and where the feed-water enters at slightly in excess of 100 degrees, it indicates that if an investment in economizers is warranted, it must prove so when supplied with feed-water at 210 degrees. This feed-water temperature has the advantage mentioned frequently, that it is easier to remove the entrained oxygen and reduce the corrosion in the boiler and economizer with feed-water at this temperature.

The guarantees made on the 20-high boilers are exceptional, but it is a little difficult to understand how a 13-high boiler with a 71 per cent. economizer having approximately 15 per cent. more heating surface than the 20-high boiler, should have the same efficiency when producing 160,000 pounds of steam, the exit temperature from the economizer being 350 degrees, and from the 20-high boiler 575 degrees, or 225 degrees higher than the exit temperature from the economizers. See Fig. 7.

Where high-grade coal is burned, with which it is easy to obtain high CO_2, the recovery in the economizers will be correspondingly low and may not be warranted; whereas, with an equally costly low grade of coal, economizers may be warranted. With pulverized coal the CO_2 is so high that the price of coal will have to be unusually high to warrant the use of economizers.

Where a common stack is used for a number of boilers, the placing of the breeching on the roof of the boiler plant will without doubt reduce the first cost, especially if the bottom of the bunker is close to the top of the boiler. This arrangement, while providing good lighting for the outside aisle of the boiler room, does not provide good ventilation for the boiler room or good lighting for the middle aisle, where it is most important to have favorable working conditions. Elevating the power-house roof and bunker will very much improve conditions in the boiler room at a small additional cost, especially if there is no longitudinal breeching in the boiler room.

Regarding double vs. single-stokered boilers, boilers equipped with single stokers are more accessible for cleaning, as access doors can be placed under the up-take end. Offsetting this, the air pressure under the stoker must be higher for equal output,

therefore requiring a greater amount of power for the forced-draft fan. The boiler can be run at much higher capacity and will have better efficiency if double stokered, at practically all ratings above 150 per cent., which is approximately the point of maximum efficiency for a single-stokered boiler.

The cost of modern boilers, especially where foundations are expensive, is so large that the total generating cost including capital cost is least when boilers are operated at comparatively

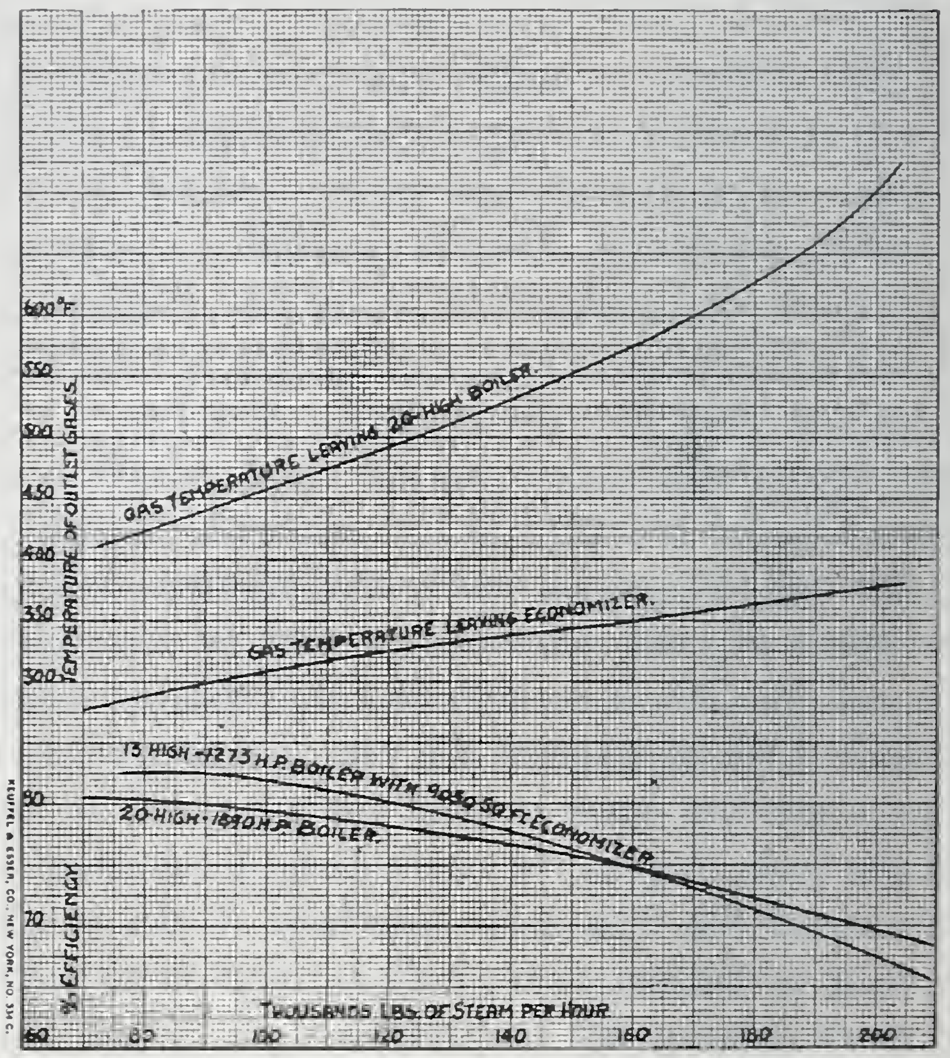

Fig. 7. Effect of Economizer.

high average ratings. The total carrying charges on a double-stokered 1890-horse-power boiler, 20 tubes high, with average foundation conditions is about $50,000 a year. This boiler is capable of producing steam about six-sevenths of the time when operated at normal maximum rating, or 7500 hours a year—one-third being at maximum rating, one-third at three-fourths of maximum rating, and the remaining one-third at one-half maximum rating.

Fig. 7 shows the relative efficiency of the 20-high boiler at 1890 horse-power when equipped with single and when equipped with double stoker. At 250 per cent. rating, the advantage in favor of the double-stokered boiler is in excess of four per cent. These curves are made on the basis of boiler guarantees. This increased economy is obtained by better combustion.

The effect of increased coal prices is to reduce the rating at

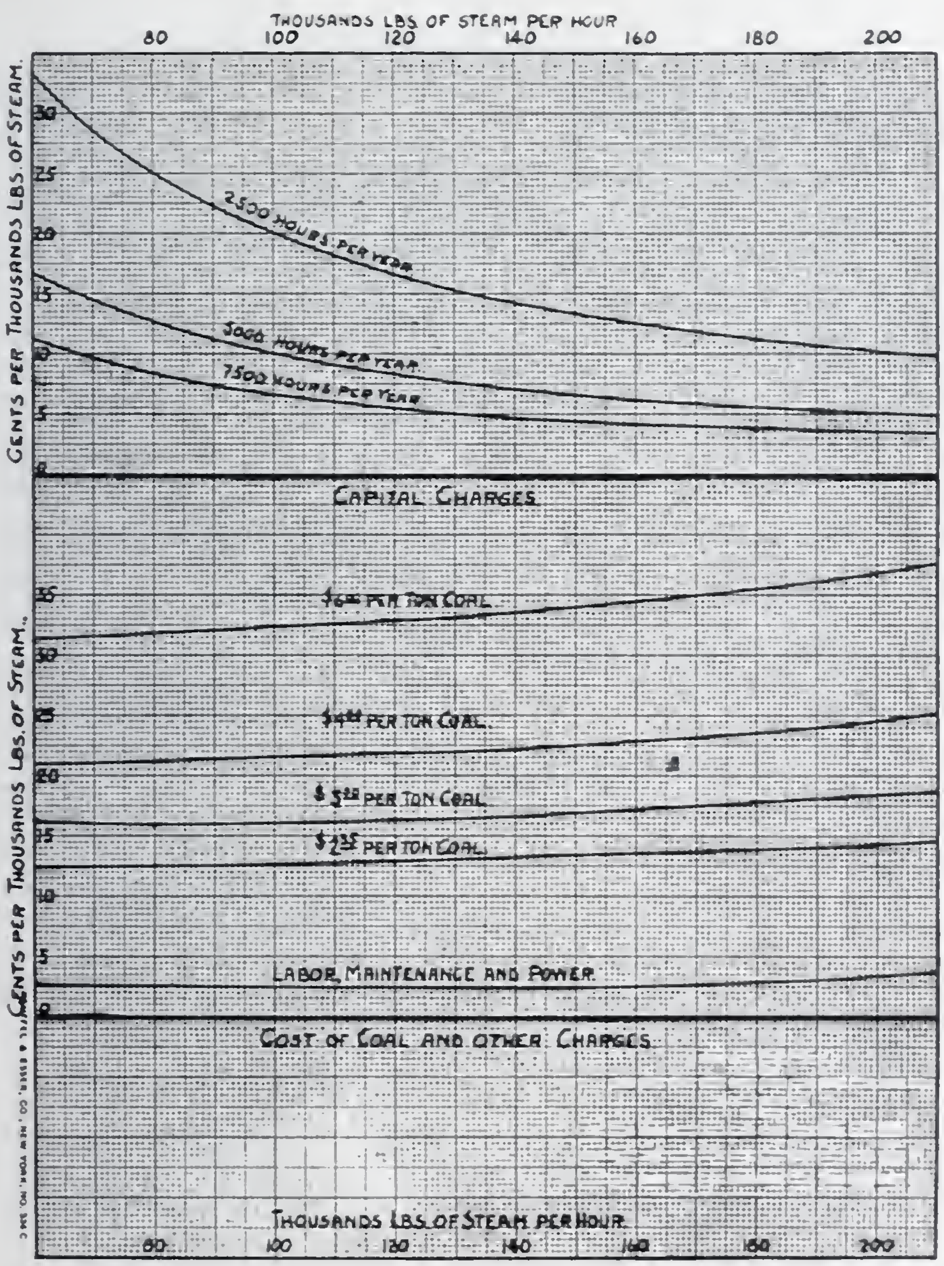

Fig. 8. Factors Affecting Total Cost of Steam.

which boilers should be operated, as the loss in efficiency at high ratings under such conditions is a more important factor.

Fig. 8 shows the interrelation of the carrying charges, the rate of steam production, and the number of hours in service. On the same diagram is also shown the relative cost of coal per

thousand pounds of steam for coal costs of $2.35, $3, $4 and $6 per ton, based on guarantees for the 20-high boiler 42 tubes wide. The other charges, including labor to operate, maintenance of boiler and equipment, and power to operate various induced and forced-draft fan and stoker motors, are also shown, and form a comparatively small item, being approximately one-twelfth of the cost of steam when coal is valued at $3 a ton.

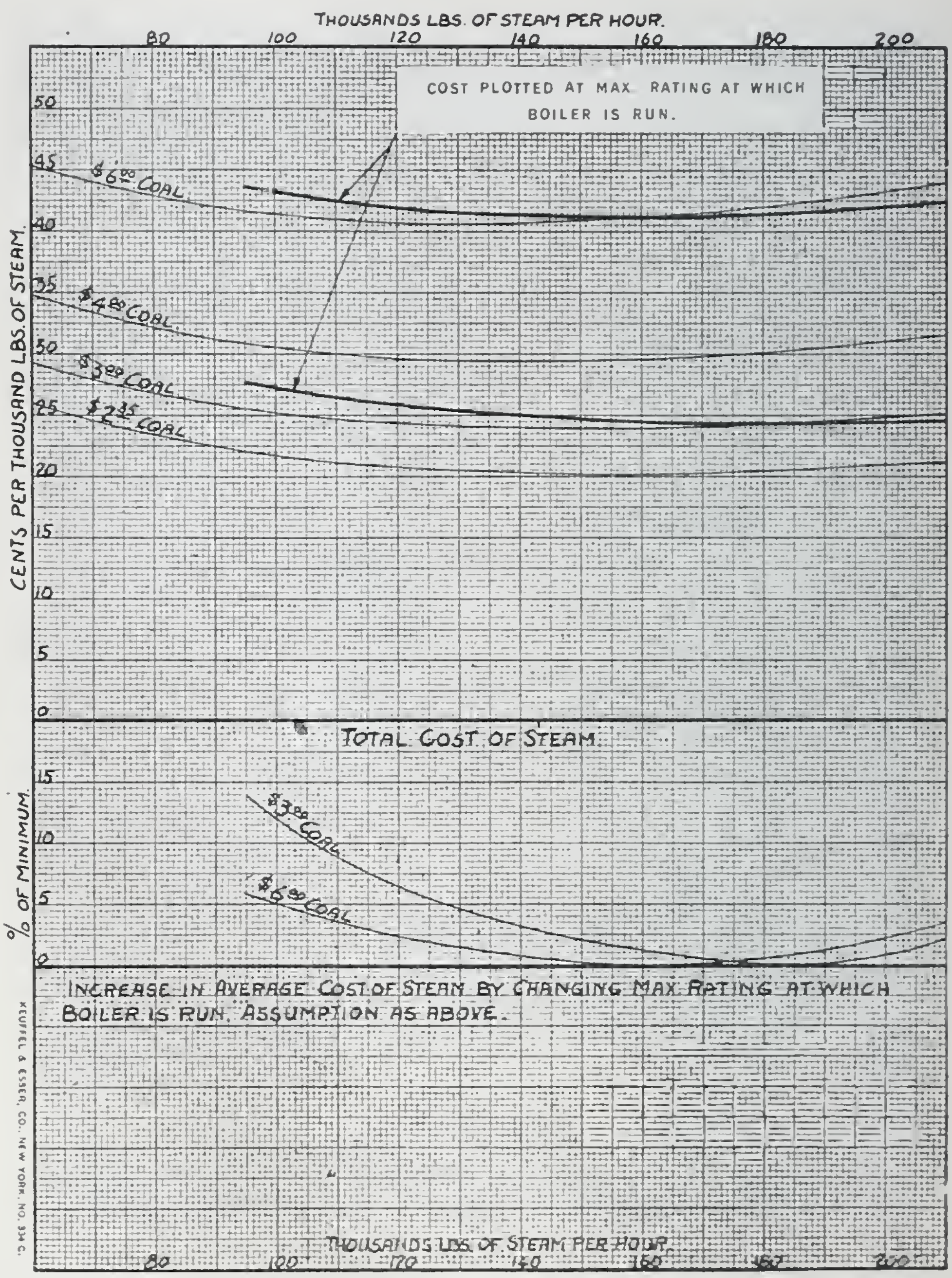

Fig. 9. Cost of Steam.

The top curves of Fig. 9 show the total cost of producing steam. The second series of curves shows the average cost of 1000 pounds of steam when the boiler is operated in accordance with the assumptions above; that is, one-third of the time at

maximum rating, one-third of the time at three-fourths of maximum rating, and the remaining one-third of the time at one-half of maximum rating, the cost being plotted at the maximum rating at which the boiler is run. The two curves on the bottom show the increase in the average cost of steam by changing the maximum rating at which the boiler is operated, the assumptions being the same.

The study indicates that the point of minimum cost of this particular boiler when burning coal costing $3 a ton is when it is operated at a maximum rating of 190,000 pounds of steam an hour. Decreasing to a maximum of 150,000 pounds an hour increases the cost of steam about 1.7 per cent., and to a maximum of 100,000 pounds an hour about 10.5 per cent. With coal at $6. the point of least cost is when the maximum output is 170,000 pounds of steam per hour, and decreasing the maximum to 100,000 pounds per hour would increase the cost of steam only 3.5 per cent.

The above studies are for a double-stokered boiler. The investment in a single-stokered boiler is smaller, due to the smaller size of the auxiliaries, air ducts, smoke flues, and bunkers, and lower expense of the stoker itself. The reduction in investment will probably not be in excess of 10 to 15 per cent., the result being that for the same investment a smaller capacity is secured per dollar invested and that there is not the overload capacity to take care of emergency conditions that there is with the double-stokered boiler.

The number of twyers in the stokers is gradually being increased; one manufacturer at the present time is offering a 25-twyer stoker. The employment of such long stokers may result in obtaining sufficient overload capacity so that with the greater simplicity of furnace and boiler rooms they will displace the double-stokered furnace. In the present designs, however, there is from 50 to 62.5 per cent. of the active grate surface in a single-stokered boiler that there is in a double-stokered boiler; and, as the reduction in initial cost is approximately 10 to 15 per cent., capacity is obtained in a double-stokered boiler for 65 to 75 per cent. of the investment that is required to obtain the same capacity in a single-stokered boiler.

The curves of operation of the double-stokered boiler indicate that the cost of operation between 100,000 and 200,000 pounds of steam is approximately the same, which would permit of boilers normally being operated under such rating as experience demonstrates gives comparative freedom from boiler trouble, and in case of emergency considerable overload capacity is available. The additional investment in stokers, fans, and flues for generating such excess is a comparatively small percentage of the initial cost. The reduction in the number of bunkers from three to one cuts the capacity of coal in storage to approximately one-half for the single-stokered boiler. The conservation of capital is particularly important when first cost is unreasonably high. This is especially true, as the advancement in the art is such that within a few years equipment installed at the present time is very likely to be peak-load equipment, as the later installations will be more efficient.

The manufacturers are recommending against extremely high ratings until further experience can be had with the circulation of water in the tubes of high boilers.

The cost of producing steam will decrease as the output from the boiler increases up to the practical limit at which the boiler can be operated, the maximum capacity being limited by the formation of clinker in the stoker, the fusing of the brickwork, or by the internal and external cleanliness of the boiler tubes. Maintenance of stoker and furnace will, of course, become excessive with slagged up boilers where sufficient draft is not provided. High boilers equipped with natural draft only were limited to a relatively low rating until the arrangement of tubes and superheaters and type of baffling as adopted in the new Hell Gate station and as purchased for the next extension to the Colfax station, were designed.

Provided the plant has a fairly heavy and steady load and the boilers are to be run at large outputs, such as the attached curve would indicate were justified, better efficiencies can be obtained with double stokers. While the boiler equipped with double stoker and with fronts parallel to the axis of the building requires three rows of bunkers in place of one required by that equipped with the single stoker, there is the advantage of having additional coal

in storage in the bunkers to take care of possible breakdowns. The amount of attendance is not measurably increased by the use of double stokers, as with these large boilers operated under steady load conditions there are comparatively few adjustments to be made. In either case there is the same number of inspection doors.

Regarding the drive of the stoker and clinker grinder, a speed range of about four to one is necessary. This can be easily secured with a direct-current motor or a pole-changing alternating-current motor. Fig. 10 shows the speed change for a 19-point

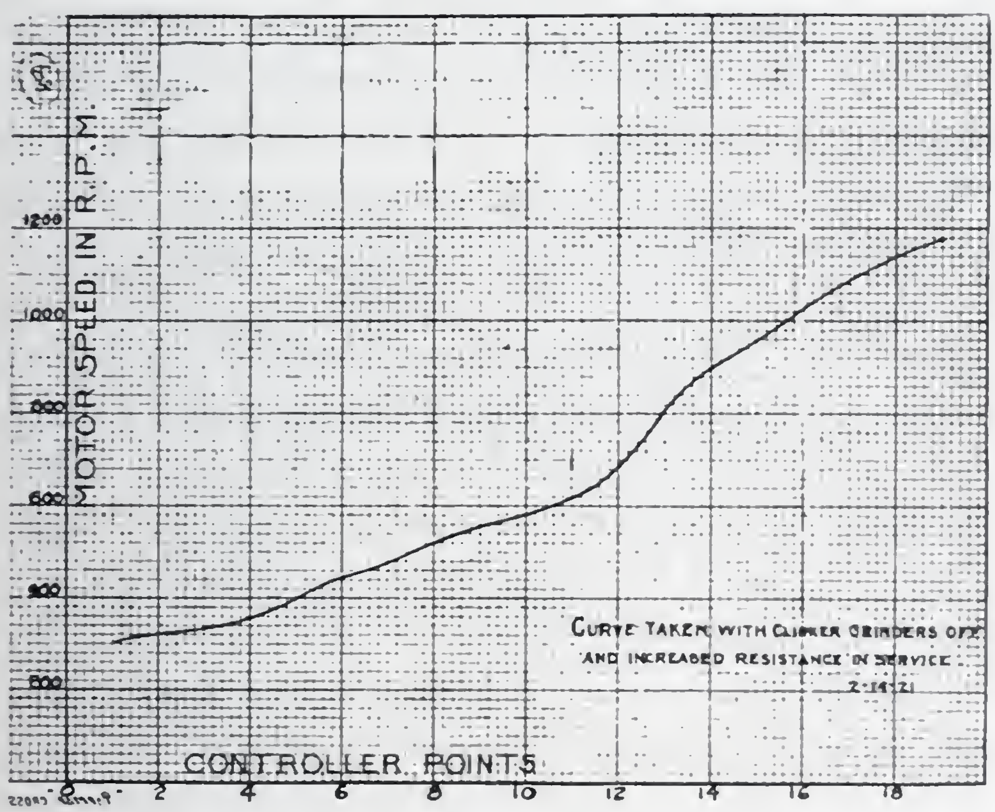

Fig. 10. Speed Regulation of Stoker Motors.

controller for the pole-changing motor. The speed change for the first 10 notches is 32 r.p.m. per notch and, for the other eight, about 70 r.p.m. per notch. The regulation obtained from these motors is satisfactory, and does not require any additional complication in the station to take care of another auxiliary voltage. The efficiency of direct-current motors is high when used as variable-speed motors; but, when the conversion losses are considered, their efficiency will be very considerably below that of the pole-changing motor.

Regarding auxiliaries, maintenance will be decreased and

easier operation will be obtained by the use of motor-driven auxiliaries. Practically all large units installed recently have duplicate auxiliaries. The great difficulty with motor-driven auxiliaries is the liability of interruption to the auxiliary on account of disturbances to the main unit. This necessitates a separate source of power for at least a portion of the auxiliaries. One circulating pump, motor-driven exciters, and motor-driven boiler-feed pumps should not be interrupted. Short interruptions to the other auxiliaries will not be serious, provided they are promptly put back in service. A non-condensing house generator can be used to advantage to supply power to the units which require the most reliable service, the remainder of the auxiliaries being fed from the main unit. The exhaust steam from the house generator can be used to heat the feed-water. The load on the house generator, to get the most economical results, should be limited to the minimum load which should have a reliable source of power, the remainder of the steam required to heat the feed-water to 210 degrees being drawn from the lower stages of the main unit unless deemed to introduce undue complication. Experiments conducted in one of the large stations indicate that sufficient steam can be bled from the low-pressure end of the large turbine to heat the feed-water to 210 degrees without materially affecting the performance of the machine. The house generator may be operated in parallel with the main units except on the approach of a storm, when it is advisable to operate it separately so that there will be no disturbance to the auxiliaries which must have a continuous supply of power. For ordinary operation a relay can be placed between the bus to which the house generator is connected and the bus fed by the house transformers which are supplied by the main unit; so, if in case of a lowering of the voltage of the main units, whether from a surge or otherwise, there is a tendency for the house generator to feed any large quantity of current to the main unit, a switch is opened separating the two buses. This arrangement has operated in practice very satisfactorily.

Auxiliaries driven by the ordinary slip-ring motor are not so susceptible to fine control as if driven by turbine; for this reason, with automatic control there is some advantage in turbine drive.

However, the brush-shifting type of alternating-current motor possesses this advantage. For use with automatic boiler control, if the slip-ring motor is worked by the automatic pressure regulator, having the ordinary type of 19 (or more) point controller, then the fine adjustment can be made by a brush-shifting motor, the latter motor being governed by furnace conditions.

Pulverized coal is attracting considerable attention. The direct application of an individual pulverizer of reliability and sufficient size to take care of individual boiler requirements, with the elimination of pulverized coal storage and feeders, would make for a very low initial cost, and permit of the remodeling of many present steam plants. In some plants located at the mine mouth, driers can be eliminated. While pulverized coal requires a larger combustion chamber, the reduction in the capacity of the induced-draft fan on account of the higher CO_2 at which it is possible to run with ordinary grades of fuel, together with the elimination of the stoker and forced-draft fan motors, will more than offset the increased power required for the pulverizers. The elimination of air ducts will tend to offset the increased cost of the furnace, and a direct-connected pulverizing plant, even allowing a spare pulverizer for every two units, is estimated to cost about as much as stoker and equipment. Neglecting the relative efficiency of the two types, this leaves maintenance as the main question between the two types of firing. Manufacturers state that low-speed mills of the ball type have a lower maintenance cost per ton than the usual stoker maintenance with Pittsburgh coals. Stoker efficiencies fall off rapidly at high ratings; whereas indications are that the curve for a pulverized-fuel-fired furnace is much flatter, and, as there is a smaller volume of gases to cool for the same output, the exit temperature is lower. This will all tend to permit of further increasing the capacity at which boilers can be run, and of reducing the labor and capital cost of producing steam. Present indications are that the recovery in economizers with pulverized fuel will be quite low; and unless a plant is run at exceptionally high load-factor and with high priced coal, economizers will not be warranted in this type of plant.

The practice of having one or more fans feeding a common duct for boilers has the disadvantage that it is difficult to run fans

in parallel. Fig. 11 shows the results of a test run by the Navy engineers, which indicates that as the difference in the speed of two fans increases there is a very rapid falling off of efficiency in the combined unit. For instance, if one fan drops in speed

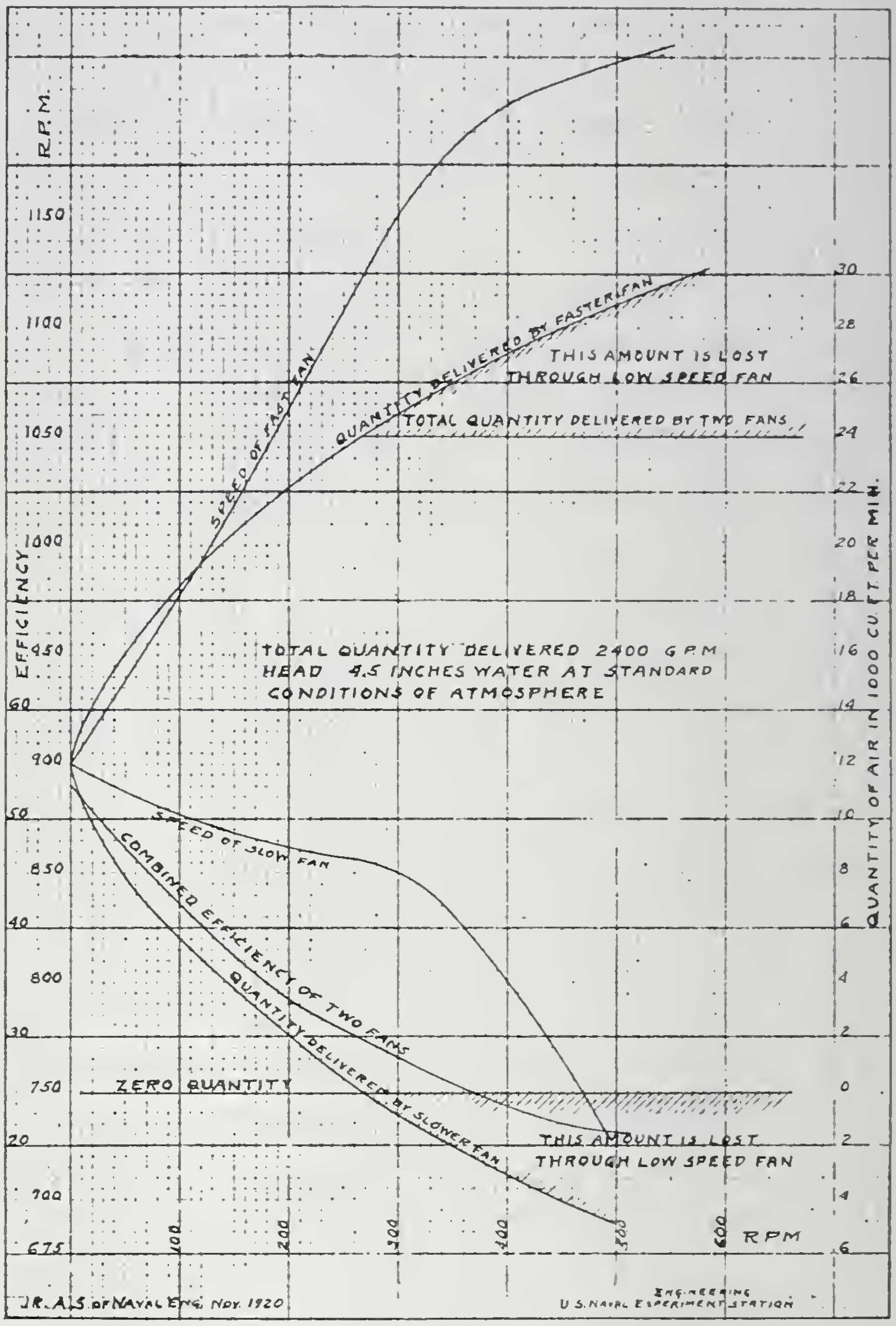

Fig. 11. Effect of Speed on Fan Performance.

from 900 to 875 r.p.m., the other fan will have to speed up to 985, and the combined efficiency of the two units will drop from 53 per cent. to 41 per cent. Care must be exercised in the selection of fans to work in parallel to see that they have stable characteristics. The foregoing indicates how readily the slightly higher

efficiency of the larger fan may be lost. In addition, it is a much easier operating proposition to regulate the motor speed than to adjust one large damper or a number of small ones.

The rotary screens should be high enough so that the screens can be operated to advantage at flood level, as it is especially at such times that screens are of the most importance.

Mr. Clarke's remarks on the simplification of piping are very appropriate. An extensive duplication of piping should not be necessary and such lay-outs have not been included in the more recently designed stations.

The electrically operated gate-valve has many advantages, but, until such a valve can be closed against the full pressure of steam on one side and opened to atmosphere on the other, the electrical operation fails in one of the principal points in which it should be an advantage. Certain tests will shortly be made on the electrically operated valve, which will help to throw light on this subject. It is probable that major modifications will be needed in the present gate-valves, or that a new type of valve such as the globe-valve or the needle-valve will have to be adopted, before the valves can be closed following a rupture in the main steam line. The main advantage of the electrically operated valve is this emergency operation and, unless it can be closed after a rupture in the pipe, the value of the electrical operation is greatly reduced.

In laying out power-stations particular attention should be given to the ease with which the various auxiliaries can be repaired. Where possible, facilities for handling the heavier parts by cranes or trolleys should be provided. In many of the more recent turbine rooms the platform around the turbine is comparatively small, and large light wells are left in the floor, thus giving access to the circulating and air pumps and in addition giving much better light and ventilation to the turbine room basement.

The direct-connected exciter with a third bearing on the inside end being coupled to the generator shaft is a source of trouble. If the exciter is to be direct connected, it should be placed directly upon an extension to the shaft of the main generator, so that in case it is not working electrically there will be

no mechanical reason for not operating it until such time as it is convenient to shut down the main unit.

Experience with small turbines under high steam pressures and temperatures has not been entirely satisfactory, and the writer would favor the elmination of these as far as possible.

Regarding the preparation of water for the boilers, the plant operated by motor-driven auxiliaries has an extremely low percentage of make-up, and evaporated water can be provided without excessive cost. In low-pressure evaporators operated at low temperature, the loss by blow down is slight and so can be made a comparatively large percentage. Experience with low-pressure evaporators operated as single effects between atmospheric pressure and a vacuum of 15 to 23 inches, indicate that they need not be opened for inspection more than once in eight or nine months, and that only very light scale will be found on them; and this, the manufacturer claims can be removed by proper cracking before the water is drawn off the evaporators and the scale exposed to the action of the air.

Condenser leakage cannot, of course, be treated by evaporators. Although it is possible to take care of this by overtreatment of the water-softening plant, it is best taken care of by an analysis of the condensate and the water in the boilers, and the addition of the necessary lime and soda-ash to the heaters. An inexpensive arrangement can be obtained for feeding in the comparatively small amount of chemical required for this purpose. This is an important item. Any time that leakage becomes large, it should be taken care of immediately for each unit, as there is no use of treating the water supplied all units to take care of the leaky condenser on the one unit, the condensate from which will not be delivered to the boilers of the other units.

Mr. J. B. Crane:* It is interesting to note that in this paper and discussion, very little attention has been paid to the turbine room, but it has been practially all devoted to the boiler room, and means of getting the steam to the turbine; indicating that while the former has become fairly well standardized, the latter is still open to widely varying designs.

*Engineer, George T. Ladd Co., Pittsburgh.

One subject not touched on in the discussion and only briefly mentioned in the paper was the question of type of boiler, and this was briefly dismissed with the statement that, of course, bent-tube boilers were not considered on account of great troubles with cleaning and maintenance, and cast headers on account of high pressure and superheat. While I hold no brief for cast headers, the fact that other engineers have chosen them and that the first instance of a failure in operation is yet to be recorded would indicate that they are at least worthy of consideration, and to make the first statement in a district where over 80 per cent. of the boilers are of bent-tube design (because the water conditions are the worst in the United States and the bent-tube boiler was adopted because it would operate longer without cleaning, respond to sudden changes in load more rapidly than the horizontal boiler, and could be cleaned in one-sixth the time of that required for the horizontal boiler) would indicate that the same reasons prevailed for picking out boilers as led to deciding on sizes of steam lines; namely that the question of time was the essence of the contract and a proper time was not available for detailed study of the various questions involved.

I recently called on an engineer who was planning to remodel his boiler room, and install 500-horse-power boilers. He had tried underfeed stokers ten years ago, but had been unable to make them work and so had built special air-blast grate-bars and was using forced draft and hand firing with very good results. He would not consider stokers. In other words, he was depending upon judgment instead of upon a careful study of modern achievements in boiler operation.

It is true of public utilities that most of them have had difficulty in securing the necessary financing, and, when the money was secured, plans for power-houses have been rushed and equipment purchased for quick delivery, or because the equipment companies were willing to wait for their money or take securities in payment, in whole or in part, for the equipment. Industrial power-plants, on the other hand, are the result of careful study and in many cases of two or three years' careful consideration of the various points involved. Any new feature that offers chances of saving is given consideration. Powdered fuel will get its big

start in the steel industry because building one power-house with boilers that can be fired with waste-heat gases, coke, different grades of coal, etc., offers such opportunities for saving in initial and operating costs, over building two or three power-houses as is now the case. The big public utility will adopt it when it has become standardized, although some of the leading engineers in the public utility field are now assembling data on by-product plants to be operated in connection with large power-houses.

I will venture to say that there are several features in connection with the design of the Colfax station that will be changed when extensions are made—even by the present engineers, and if other engineers were called in they would find just as many errors in design as the author is finding at Buffalo.

Mr. John A. Hunter:* I have listened with a great deal of interest, both to Mr. Clarke and the other gentlemen who have presented discussions. Mr. Clarke has prepared a very excellent paper, covering in a general way all the essential points entering into power-plant design. I believe, however, the paper would have been of more interest if he had given in detail his reasons for installing or not installing certain equipment in the Colfax station. For example, he states that the installation of economizers is not justified. This may be true in large power-plants using high steam pressures, and not taking advantage of the counter-flow principle of economizers, but in steel-mill boiler houses, where lower steam pressures prevail, cast-iron economizers using the counter-flow principle can be used and their installation shows a very good return on the investment.

Mr. F. F. Espenschied:† We have near Pittsburgh two large, new power plants—one the Duquesne Light Company's plant, so well described by Mr. Clarke, and the other the West Penn Company's plant, touched upon by Mr. Bell. These two plants are of comparable size, contain the latest ideas and equipment and are used for similar service. They are on the same

*Steam and Sanitary Engineer, American Sheet & Tin Plate Co., Pittsburgh.

†District Representative, Commercial Truck Company, Pittsburgh

river and use practically the same fuel. Each designer embodied his own ideas as to steam pressure, superheat, boiler rating and general arrangement. The object of each plant is to make cheaper power and it would be very interesting to know the actual results of operation—that is, generating costs, capital charges, and operating experience. So far, we have heard only of engineering details and I would like to know the final result of all this.

MR. ROBERT LACY:* The writer understood Mr. Clarke to say that the only boiler for power-station work was one having wrought-steel headers. In this connection we would call your attention to the fact that the "Springfield" boiler is very similar to the boilers at the Colfax and Seward stations but has headers of cast-steel. The headers are made by electric smelting and are subjected to a thorough physical test before being used. The anaylsis of the steel is given in paragraph 85, Medium Classification, Report of Boiler Code Committee, American Society of Mechanical Engineers.

We would further state that we have never replaced a header; also that these headers have been tested to a hydraulic pressure of 1700 pounds per square inch without deformation.

The "Springfield" design of boiler, after exhaustive investigation and tests by the engineers for the United Electric Light & Power Company, New York, was officially adopted by them, and we now have partially erected twelve 1890-horse-power boilers at their Hell Gate station. These boilers are built for a working pressure of 300 pounds per square inch and over 200 degrees F. superheat. These boilers represent half the total plant and the present installation is about twice as large as the present installation at Colfax.

MR. F. J. CROLIUS:† Mr. Clarke brings up the question of *cost* of pulverized coal. He is quite right, and I agree with him that coal cannot be dried, pulverized, distributed, and fired under boilers in the average power-house at the same cost as that of

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†Steam Engineer, Homestead Works, Carnegie Steel Co., Munhall, Pa.

operating stokers and fans; but his comparison assumes the present highly expensive, complicated systems in which dried coal and finely ground coal must be delivered to the distributing system. It is not a requirement of the combustion unit that coal be finely ground or dry; it is the limitation of the distributing system. By eliminating the distributing system, pulverized coal can be delivered to boilers at a cost lower than that of stoker and fan operation, and the installation will be no more costly than stoker equipment.

We have been firing undried, coarsely ground coal under a number of boilers for a year and a half, and our actual pulverizing costs have been less than the forty cents a ton which seems to be the figure accepted as charged against stoker operation.

I am merely emphasizing the point that present pulverizer installations should not be taken as a criterion of costs necessary to the complete operation. Coal can be delivered and burned in furnaces as cheaply as, or more cheaply than, the complete costs of operating stoker and fans, all factors considered.

Mr. C. W. E. Clarke: Mr. Van Deventer regrets that I have not given in more detail the processes of reasoning or computation which led to the solution of various problems outlined in the paper. About all I can say is that many of these conclusions are the results of continuous experience in this line of work and I am not in the least interested in a minute discussion of any one particular element in a power situation. Results speak for themselves and when one produces a power-generating plant economical in first cost and both economical and reliable in operation, it is immaterial that some other engineer believes some minor item could have been done in a cheaper or a different way. The solution of the entire problem of converting coal into kilowatts is the one under discussion, not the solution of the more minor details which can not effectually change the final answer.

Referring to Mr. Van Deventer's comments on the height of the stack—that is fundamentally controlled by the draft loss in the boiler and the rating at which you wish to run. Cutting down the stack would not help you in your ability to run half that load or a quarter that load. You might have a stack just as high if you had a boiler that showed that much loss.

There is no advantage in an induced-draft system which will operate at 400 per cent. when the stoker permits of only 300 per cent. The limiting factor at Colfax is stoker capacity, not stack capacity. Has he ever had any experience in the construction and operation of fans which will operate 2082-horse-power boilers at 500 per cent.? Has he experienced what their size would be and what would be encountered in running them?

Relative to the question of velocity in the steam line, if we were to go through any such analyses as Mr. Van Deventer suggests for a development the size of Colfax, which was to be running in 10 or 12 months, the steam never would get to the station. We do not go into such fine calculations. The size of the lines is based on judgment and experience, and almost on judgment alone, with certain limits of velocity not to be exceeded.

Our experience as to economizers might answer Mr. Van Deventer's discussion on that subject. At the time the Colfax station of the Duquesne Light Company was designed, it was found that to equip one 60,000-kilowatt unit with economizers would cost $424,600; the net operating saving due to the installation was $43,300 a year; the cost of maintenance was $7000 a year; for fan operation and attendants $3300 a year, leaving a net saving of $33,000 a year, or 7.8 per cent. on the additional investment. Money for this plant cost close to 15 per cent., so it can well be seen why economizers were omitted. The above figures are based on coal at $3.50 a ton and on seven boilers 16 tubes high, each containing 13,105 square feet. of heating surface. With coal at a cost of about seven dollars a ton, economizers would have begun to make a financial return to the company.

The difficulty with most figures made on economizer installations is that they are made in just such shape as Mr. Van Deventer has made his. Commenting in detail on his Table II, I believe that if proper analysis were made of the situation included under costs which accrue when economizers are installed these results will not be very different from those quoted above. I would like to call his attention specifically to the fact that he has included no additional cost whatever for extra feed pump capacity, piping, smoke flues, and covering—items which would total to much more than the additional cost which he shows for econo-

mizers in "Extra cost of building". The item of $2000 for building is less than 10 per cent. of what would be required to take care of the situation adequately.

Replying to Mr. Pendleton on economizers, I would call attention to the fact that he is talking about a type of economizer of which there are but two in service, serving about 700 horse-power of boiler installations; one in Albany and one in Cleveland. I understand that his company has an order for two additional machines for the Detroit Edison Company, which will serve a total capacity of about 5000 horse-power and which should be running some time about the latter part of this year. Under these conditions I think that it is not necessary to comment further, except to say that the type of machine he is describing is still in the experimental stage and the success of the installation must rest in this case, as with any other piece of apparatus of this character, upon the returns received from the money invested.

I might add a little more light on this economizer situation. An analysis of the Colfax plant, taking seven economizer schemes into account—which included a 10-high boiler with a 72 per cent. economizer, a 14-high and a 16-high boiler with 60 per cent. economizer, and a class "W" boiler similar to that used in Detroit with a 45 per cent. economizer—showed that the first plan would earn seven per cent. on the money invested after the economizer was taken care of. That was based on coal at $3.50.

The proper solution of the economizer problem in any situation, be it a steel-mill plant or a central-station plant, can be settled only by a careful consideration of the economics of the situation. There are no doubt many industrial situations which warrant the use of economizers.

Replying to Mr. Lacy's inquiry as to my statements relative to boilers for large power-stations, I would refer him to the first paragraph under the heading "Boilers" on page 117.

Referring to Mr. Crane's comments relative to bent-tube boilers and the large number in use in the Pittsburgh district, he doubtless would be interested to know that when bids were received on boilers for the Colfax station, six different boilers were considered. Among those were three different types and two of

those were bent-tube types. Straight-tube boilers were decided upon as being better suited to the situation.

Mr. Crane might be interested in the following statistics for the Pittsburgh district, covering only the state of Pennsylvania. One large manufacturer reports a total of 964,185 horse-power of straight-tube boilers installed as against 387,869 horse-power of bent-tube boilers.

The second unit is now going ahead at Colfax station. When this installation is finished Mr. Crane will have the opportunity to see that practically no fundamental changes have been made in this installation as compared with the first. I do not understand Mr. Crane's reference to "errors" which he is finding in the installation at Buffalo.

I suggest that Mr. Bell be given an opportunity to present a detailed paper on the Springdale station of the West Penn Power Company. It should surely prove interesting to the Society. Mr. Espenschied says it is comparable in size and cost with the Colfax station. I do not believe even Mr. Bell will agree with that.

POWDERED COAL AS FUEL IN STEAM PLANTS

By Henry Kreisinger* and John Blizard†

It is now definitely established by experiment that a higher thermal efficiency can be obtained in steam plants by burning coal in powdered form than by burning it by any other method. It can be said also that in many steam plants, steam can be made more cheaply with powdered coal than when burning coal by any other method.

The reasons for the high thermal efficiency of powdered coal are as follows:

1. Very nearly complete combustion can be obtained with slight excess of air.

2. Variation in load over a wide range can be readily followed, and at the same time furnace conditions giving high efficiency can be maintained continuously and easily.

3. No coal need be burned on banked boilers during the low-load periods.

It is apparent that the first two of the above conditions of high efficiency depend entirely on proper burner and furnace design; in other words, it is the furnace that makes high efficiency possible. No matter how cheaply or how easily powdered coal is prepared, if the coal cannot be burned efficiently, the plant is a failure. For this reason a large part of this paper is devoted to furnace design.

1. *Combustion.* Very nearly complete combustion with low excess of air is the first requisite of high thermal efficiency. Numerous tests show that with powdered coal, combustion complete within one per cent. can be obtained with 20 per cent. excess air. This one per cent. of incomplete combustion includes both the gaseous combustible as CO in the flue-gases, and the unburned carbon in the ashes.

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†Fuel Engineer, Pittsburgh Experiment Station, U. S. Bureau of Mines.

Table I gives the averages of the principal results of three groups of tests made at the Oneida Street station of the Milwaukee Electric Railway and Light Company. The first vertical column given the averages of a group of five tests made with dried coal; the second column gives the averages of three tests made with undried coal; and the third column the averages of two tests made with coarse coal. Each test lasted 24 hours. The tests were made on a three-pass Edge Moor boiler rated at 468 boiler horse-power, and equipped with a "Lopulco" furnace designed by the Locomotive Pulverized Fuel Company. The furnace is shown in Fig. 1. The coils near the bottom constitute an experimental water screen from which the screen shown in Fig. 4 was developed. This furnace was recently rebuilt on lines similar to the design of the furnace shown in Fig. 4.

During this series of tests a thorough study was made of the combustion of pulverized coal and the proper design of furnaces for burning pulverized coal. Fig. 2 shows a group of isothermal lines determined by measurements with platinum thermo-couples. The highest temperature is shown to be a short distance above the shelf, where the combustion is most intense, due to violent mixing of the gases and the particles of coal caused by the change in the direction of the flow, and where the flame thus far in its path from the burner has been unable to radiate a large proportion of its heat to either the cooling coil beneath it or the lower row of tubes above it.

By referring to items 12 and 13 in Table I it will be seen that the excess of air averaged 21, 18, and 22 per cent., and the incomplete combustion loss averaged 0.8, 0.3, and 0.8 per cent. for the three groups of tests. The overall thermal efficiency of the boiler was 82.2, 80.8, and 82.2 per cent. based on gross heat value of the coal, and 85.3, 83.9, and 85.3 per cent. based on net heat value of the coal.

Fig. 3 shows graphically the results of another series of 26 tests made at the Lakeside station of The Milwaukee Electric Railway and Light Company. All of these tests were made on

TABLE I. SUMMARY OF RESULTS OF THREE GROUPS OF TESTS WITH POWDERED COAL

1.	Condition of coal	Dried	Undried	Coarse
2.	Number of tests averaged	5	3	2
3.	Average duration of tests, hours	23.26	21.16	24.38
4.	Moisture in coal as burned, per cent.	2.75	8.05	3.53
5.	Coal through 200-mesh, per cent.	71.3	70.8	64.7
6.	Coal through 100-mesh, per cent.	94.72	94.90	89.7
7.	Rating, per cent.	117.0	112.8	113.4
8.	Carbon dioxid, per cent. by volume	15.1	15.6	14.85
9.	Oxygen, per cent. by volume	3.5	3.2	3.85
10.	Carbon monoxid, per cent. by volume	0.02	0.0	0.05
11.	Temperature of flue-gases, degrees F.	484	488	478
12.	Per cent. of excess air	21	18	22
13.	Incomplete combustion loss, per cent.	0.8	0.3	0.8
14.	Boiler efficiency based on gross calorific value of coal, per cent.	82.2	80.8	82.2
15.	Boiler efficiency based on net calorific value of coal, per cent.	85.3	83.9	85.3

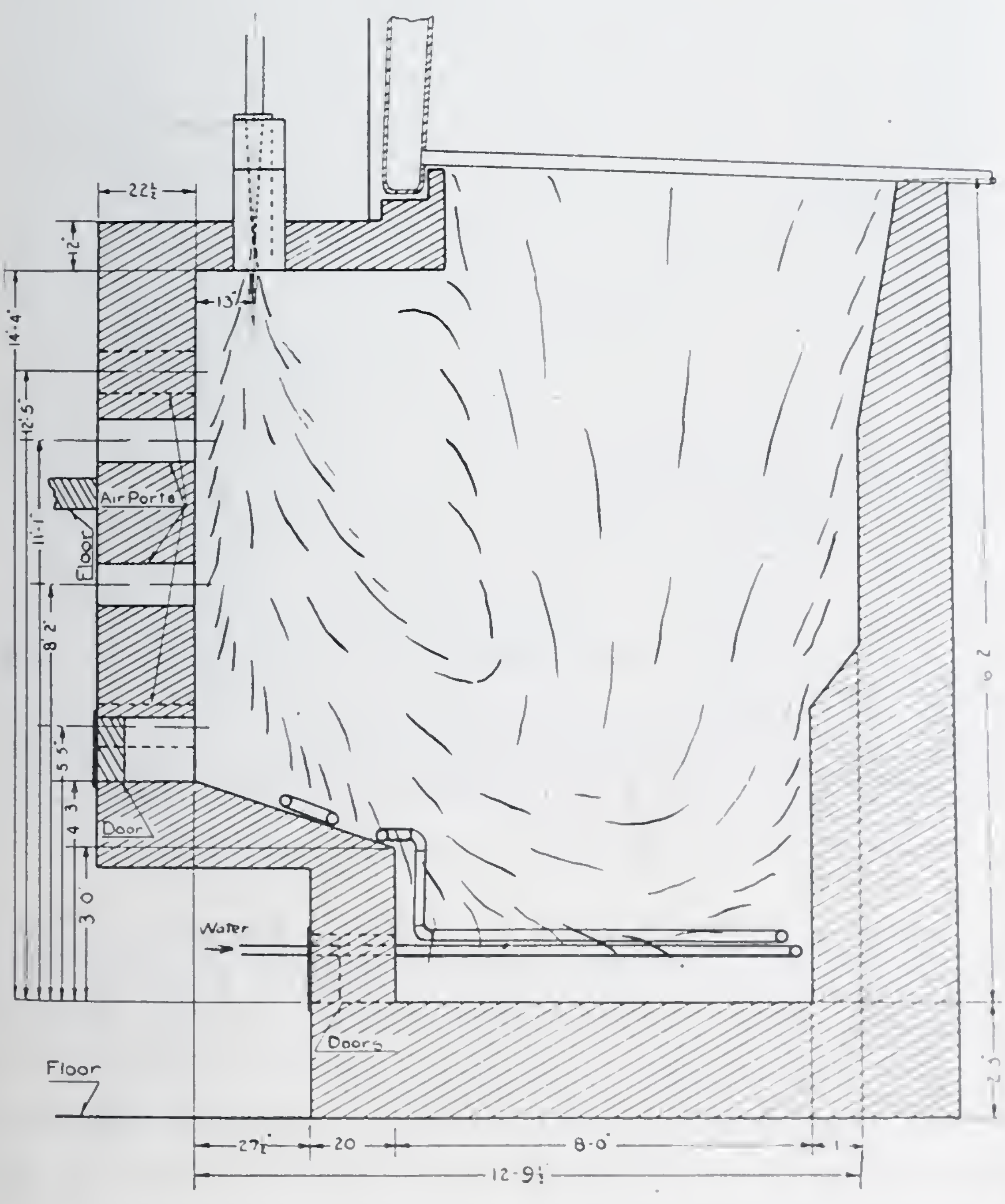


Fig. 1. Longitudinal Cross-Section of Furnace Burning Powdered Coal.

the same four-pass Edge Moor boiler rated at 1338 boiler horsepower (shown in Fig. 4) and were of 24 hours duration. The results are plotted on the percentage of rating as abscissæ. When two or more tests were made at nearly the same rating, the results were averaged and the averages were used in the plotting. This

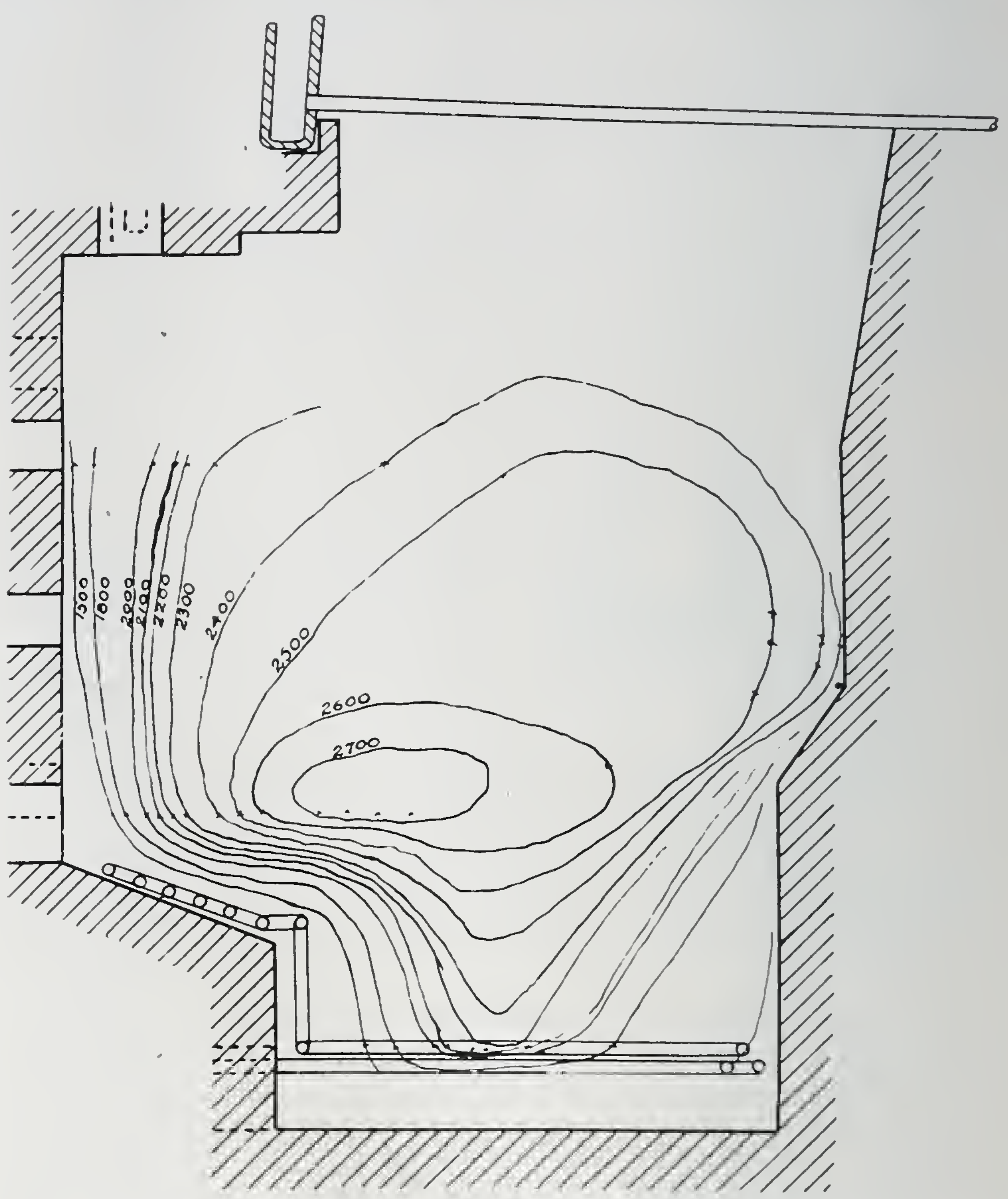


Fig. 2. Isothermal Lines in Operation of Furnace Burning Powdered Coal.

series of tests covers a range of from 135 to 255 per cent. of the boiler's rated capacity. The highest efficiency was obtained at about 150 per cent. of rated capacity. Even when the rating was increased to 255 per cent. an efficiency of 82 per cent. was still obtained. This efficiency, shown by the lowest efficiency curve in Fig. 3, is based on the gross calorific value. The curve above

it shows the efficiency based on the net calorific value, and is seen to be about 3.5 per cent. higher. The curve at the top shows the overall thermal efficiency of the boiler and economizer based on

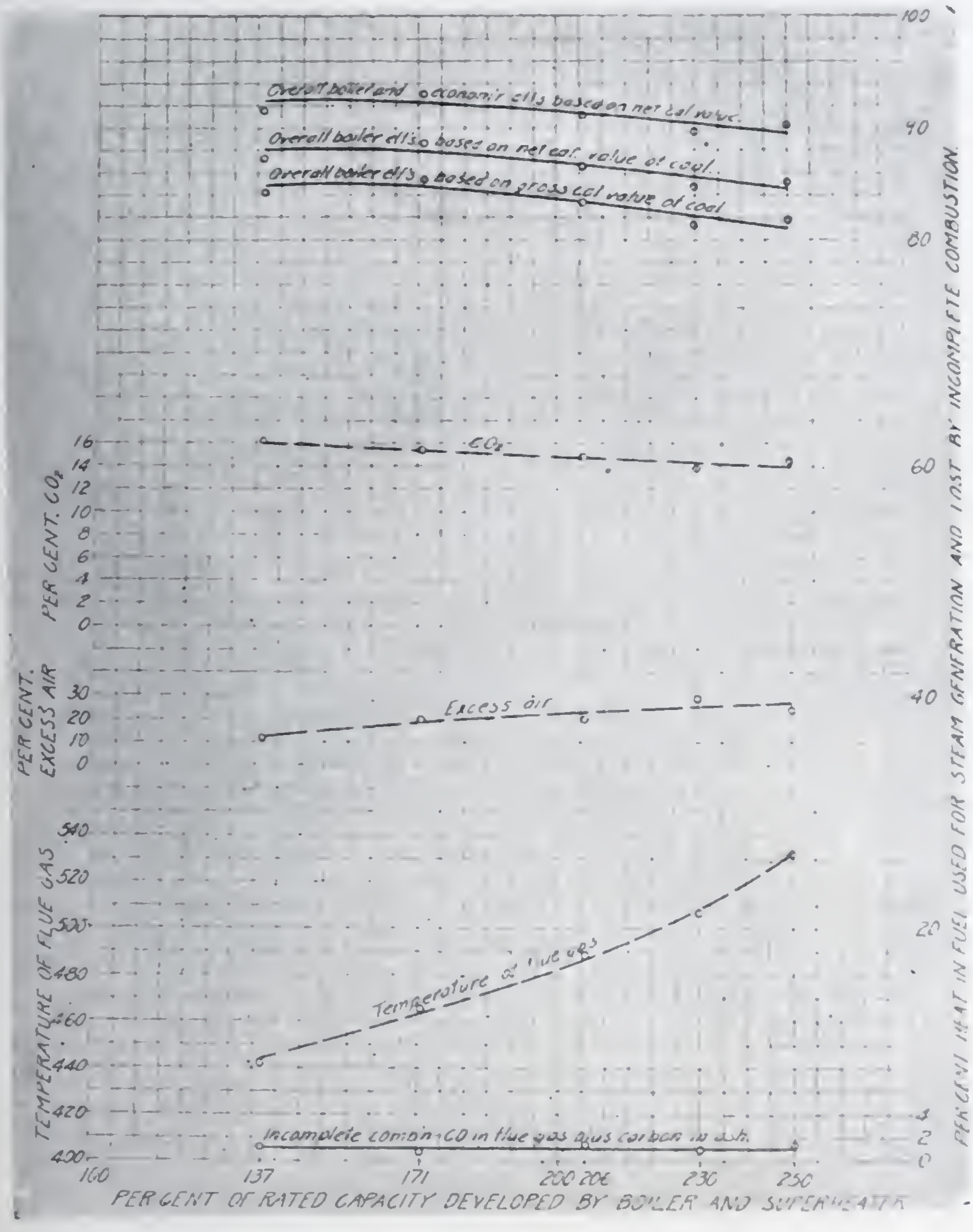


Fig. 3. Results of Tests with Powdered Coal.

the net calorific value, which for practically all the tests was well over 90 per cent.—a very high efficiency.

It will be noted on the two curves of Fig. 3, giving the excess air and the incomplete combustion, that on this series of tests the excess air was as low as 10 per cent., did not exceed 38 per cent., and averaged 21 per cent. The incomplete combustion heat loss did not exceed 1.4 per cent. It is plotted on the same scale as the

thermal efficiency and is shown by comparison to be extremely small.

Complete combustion with low excess air is ordinarily accompanied by high furnace temperature, and high furnace temperature destroys the furnace lining, and causes the ash to fuse on the bottom of the furnace, whence it is difficult to remove.

We have then the following chain of reasoning. On account of the cost of preparation, powdered coal must be burned with high efficiency in order to compete successfully with other methods of burning coal. High efficiency is obtained by burning the coal completely with low excess of air. Low excess of air causes high furnace temperature which in turn is destructive to the furnace lining and makes removal of refuse difficult. Therefore, the success of pulverized coal under steam boilers depends on the solution of these two problems:

a. Prevention of the destruction of the furnace lining.
b. Easy removal of ash from the furnace.

The ash of most steam coal fuses and runs like molten iron at a temperature of 2300 to 2400 degrees F. When the temperature of the furnace lining exceeds that of the molten ash, the slag penetrates into the brick and washes it away; but if the temperature of the furnace lining be kept below that of the running ash, the slag on falling on the surface of the furnace lining is cooled to the temperature of the lining and becomes very viscous paste. In this viscous state the ash does not penetrate into the brick and does not wash it away, but forms a soft protective coating. To prevent this erosion of brickwork by slag, therefore, the furnace lining must be kept below the temperature of running ash.

If the ash is to be removed easily from the furnace, the falling particles of the molten ash must be cooled and solidified before they reach the bottom of the furnace, and the bottom itself must be kept below the temperature at which the ash is sticky. Under such conditions the ash deposited is in granular form and can be removed easily.

Fig. 4, which shows a furnace designed to operate on these principles, is the furnace of the Lakeside plant of The Milwaukee

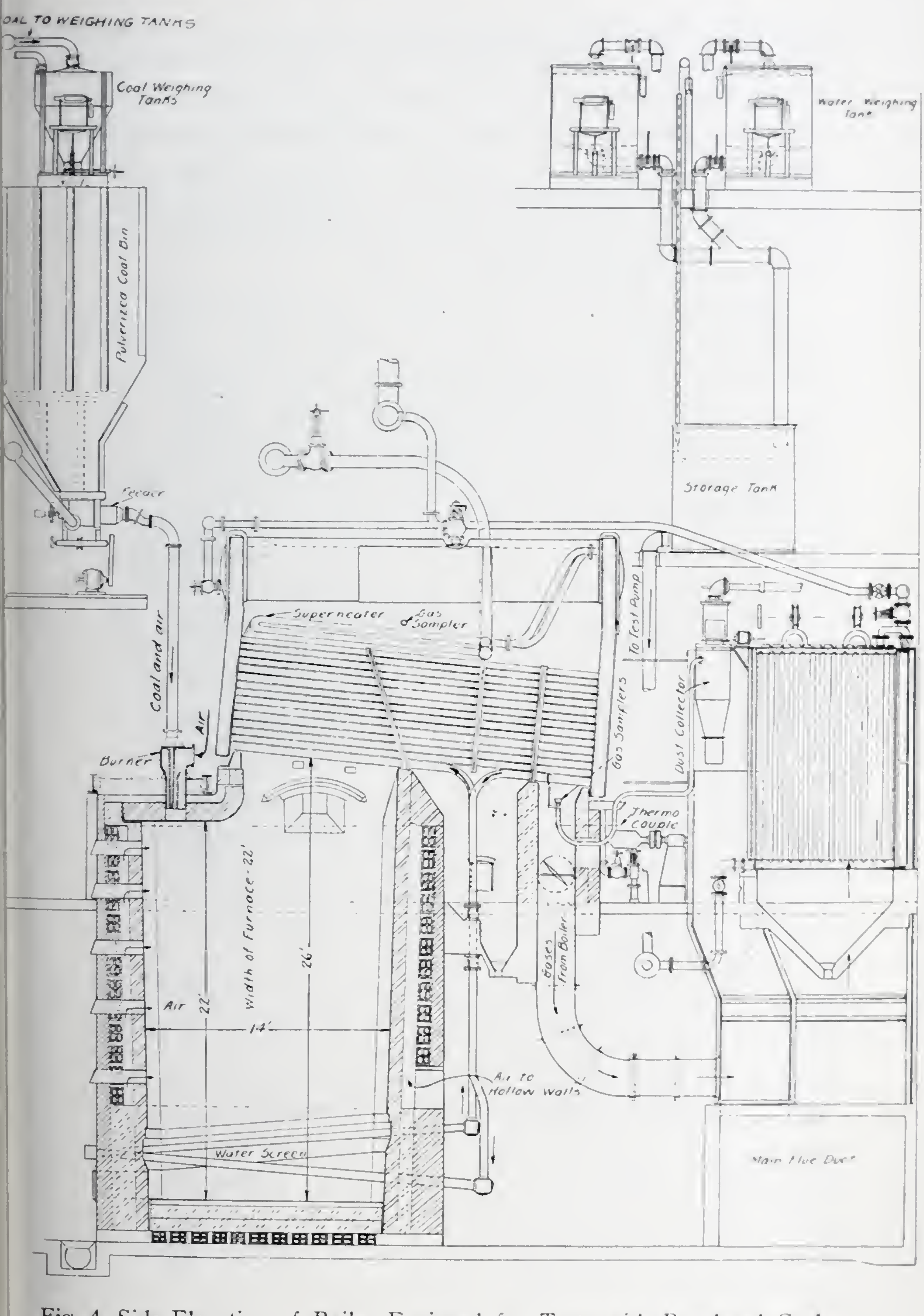


Fig. 4. Side Elevation of Boiler Equipped for Tests with Powdered Coal.

Electric Railway and Light Company, and the one on which the tests, the results of which are shown in Fig. 3, were made. The furnace has a water screen connected to the boiler, and hollow walls for supplying 65 per cent. of the air used in combustion. Its design was developed co-operatively by the Research Department of the Combustion Engineering Corporation, the Engineering Staff of The Milwaukee Electric Railway and Light Company, and the United States Bureau of Mines.

The furnace lining is nine inches thick and is separated from the outside walls by air spaces nine inches wide. About 65 per cent. of the air needed for combustion passes through these air spaces, absorbs heat from the furnace lining and thus keeps it below the temperature of the running slag. The air enters through the openings in the rear wall of the furnace, passes through the air channels in the two side walls, meets in the passages of the front wall, and enters the furnace through air openings in the front wall. The air takes the heat out of the furnace lining, where it is not wanted, and puts it into the combustion space where it is wanted. While passing through the hollow walls the air is heated to an average temperature of about 450 degrees F., and thus keeps the temperature of the furnace lining below that of the running slag and prevents the erosion of the brick.

In addition to the benefits derived by cooling the furnace lining, the passage of air through the hollow walls greatly reduces the radiation losses by maintaining the outside surface of the furnace walls at a temperature not more than 15 degrees F. above the temperature of the surrounding air.

The bottom of the furnace is kept cool by means of a water screen placed about three feet above the bottom. This screen consists of two rows of four-inch tubes rolled into a common header in front. In the rear each row of tubes connects to a separate header placed at such an elevation that while both rows are inclined relatively to each other, each row is inclined to the horizontal at the same angle as the tubes in the boiler are inclined. This slope gives the water in the tubes a positive circulation. Water comes down from the rear water-leg of the boiler into the lower row of tubes, passes through it to the front header

of the screen, then enters the upper row of tubes and passes through into the upper header in the rear of the furnace. From this header the water and steam rise into the boiler tubes over the fire and enter the front water-leg of the boiler.

The water screen absorbs heat at the rate of 40,000 to 50,000 B.t.u. per square foot of heating surface per hour. In other words, it develops one boiler horse-power on less than a square foot of heating surface. The screens at the Lakeside plant have an effective heating surface of 300 square feet, and develop about 400 boiler horse-power.

The effect of the screen in the furnace is threefold:

a. It absorbs from the flames by radiation an amount of heat equivalent to about 400 boiler horse-power, and therefore makes the furnace temperature considerably lower and helps to keep the temperature of the furnace lining below that of the running slag.

b. It cools and freezes the particles of the molten ash, as they fall through it to the bottom of the furnace, so that they are deposited in granular form.

c. It partly screens the bottom of the furnace from radiation from the flames, and also absorbs some heat from the bottom by radiation, thus keeping it below the temperature at which the ash is sticky. Thus it is possible with this design of furnace to maintain continually furnace conditions which give high efficiency.

Fig. 5 shows the latest design of a burner for burning pulverized coal. This type of burner is installed in the Lakeside and Oneida Street stations of The Milwaukee Electric Railway and Light Company. In these installations about 15 per cent. of the air needed for combustion is supplied with the coal under a pressure of 7 to 12 inches of water. About 15 to 20 per cent. of the air is supplied through the burner around the nozzle, and 65 to 70 per cent. through the hollow walls.

2. *Variation in Load.* With powdered coal the boiler operator easily controls the rate of combustion and air supply, and therefore the variation in the load over a wide range can be easily followed. The rate of combustion is directly pro-

portional to the speed of the feeders and the coal burns as fast as it is fed to the furnace, which contains less than 10 pounds of coal at any one time. About 80 per cent. of the air needed for combustion is supplied by the draft in the furnace, and the quantity required is controlled simply by regulating the draft. Fig. 6 shows graphically how nearly constant furnace conditions can be maintained with a variable load. The diagrams give the

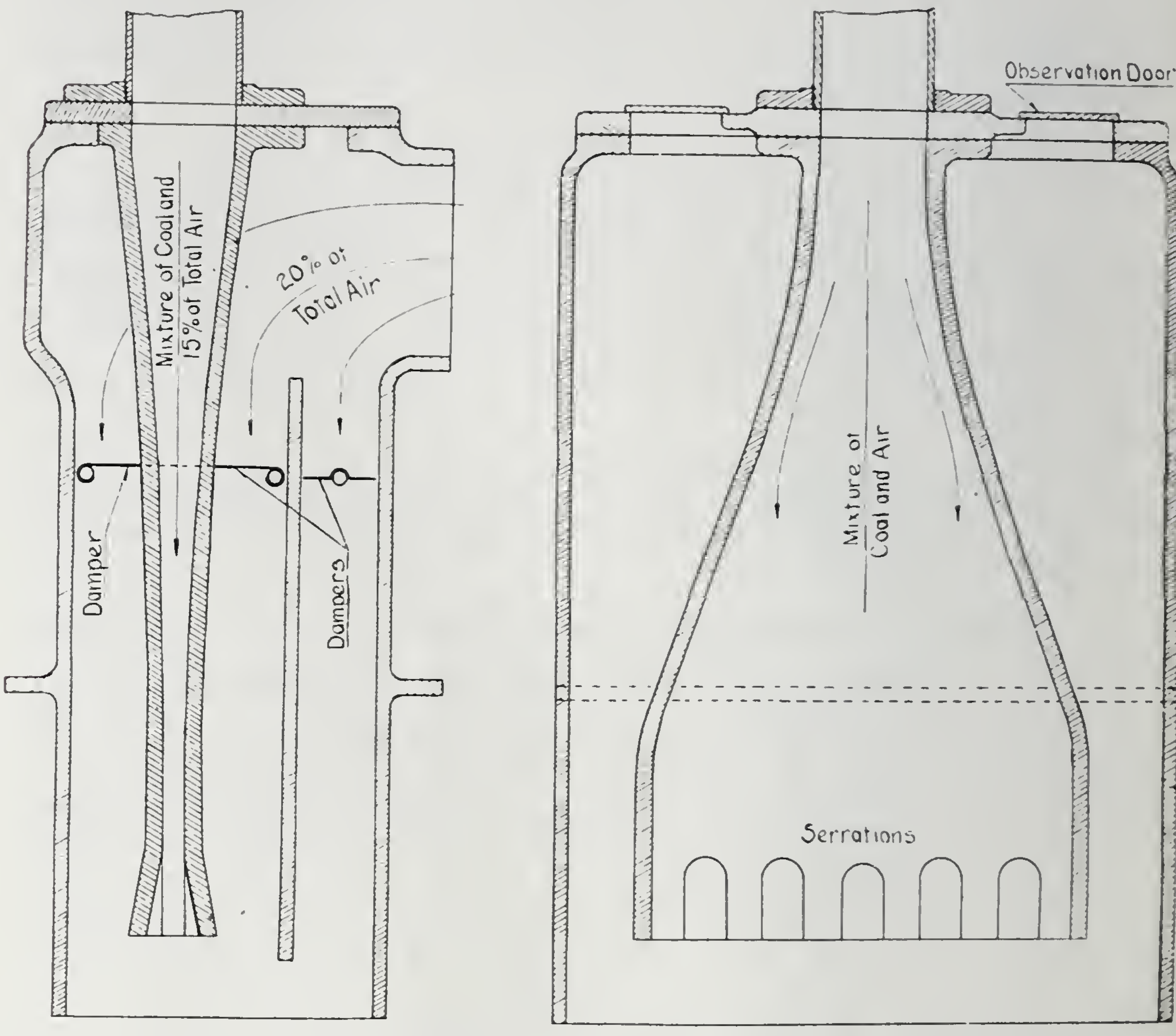


Fig. 5. Burner for Powdered Coal.

principal observations on a nine-day test made with two 768-horse-power Stirling boilers burning powdered coal, at the plant of the St. Joseph Lead Company, Rivermines, Missouri; and show how variations in load can easily be followed with good furnace conditions. The tests were made under the actual operating load conditions. The regulation of the coal feed and the furnace draft was handled by the regular plant fireman.

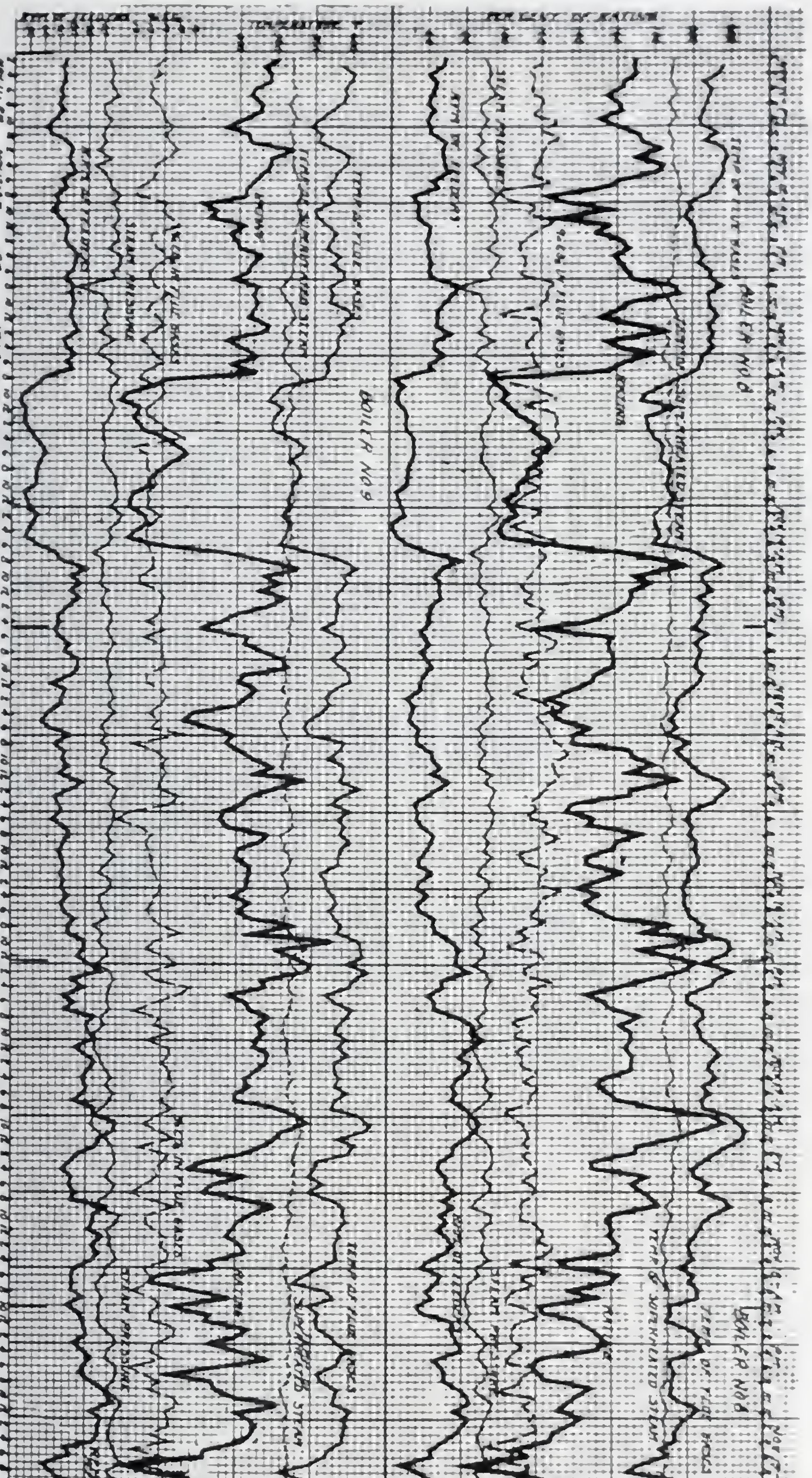


Fig. 6. Uniformity of Furnace Conditions with Variable Load.

There was also a battery of Heine boilers equipped with chain-grate stokers in this plant. These stoker-fired boilers carried a steady load while the two Stirling boilers with powdered coal took the variation. The furnaces of the Stirling boilers are of somewhat older design and not having the water screen, cannot be operated with as low excess air as the furnace shown in Fig. 4; nevertheless, the efficiency was good. Table II gives the average of the principal results of the entire tests. The efficiency is expressed in two ways, one based on the high or gross heat value of the coal and the other on the low or net heat value. The efficiency of this test is the ratio of the heat absorbed by the boiler, divided by the heat in the coal delivered to the feeders.

TABLE II. SUMMARY OF RESULTS OF NINE-DAY TEST WITH POWDERED COAL

		First 5 days of test	Last 4 days of test
1.	Condition of coal	Dried	Undried
2.	Average rating, per cent.	155	156
3.	Temperature of flue-gases, degrees F.	562	567
4.	Temperature of superheated steam, degrees F.	535	538
5.	Per cent. of carbon dioxid in flue-gases	13.7	13.6
6.	Per cent. of excess air	32	32
7.	Incomplete combustion loss, per cent.	1.0	1.3
8.	Boiler efficiency based on gross calorific value of coal, per cent.	78.8	78.7
9.	Boiler efficiency based on net calorific value of coal, per cent.	81.9	81.8

3. *Banked Boilers.* Powdered coal ignites with the same ease as gas, and fires under a banked boiler can be started and the boiler brought up to full operating conditions usually in less than 20 minutes, which makes it unnecessary to burn any coal while boilers are banked; thus powdered coal offers a possibility of considerable saving in plants where boilers have to be kept in a banked condition over long periods.

In the present state of the art of preparation of pulverized coal, the power required to pulverize coal is about 14.5 kilowatt-hours per ton when the coal is dried. This figure includes the power used to convey the coal from the pulverizing mill to the feeder bins. When the coal is dried in a drier, the power required to operate the drier is about 1.7 kilowatt-hours per ton. In addition to this, about 1.25 per cent. of the coal dried is burned to

heat the drier. If the coal does not contain too much surface moisture, it can be successfully pulverized without previously being dried, and the power required to pulverize the coal is about equal to the total power needed to operate the drier and the pulverizing mill with dried coal, or about 16.2 kilowatt-hours per ton, but the coal that would be used in the drying process is saved.

In the past there has been a tendency to emphasize the necessity of drying the coal to a very low percentage of moisture and of pulverizing it very finely. This necessity has been largely due to improper furnace and burner design and the inability of such furnaces to burn undried and coarsely pulverized coal. Recently, however, with some coals the process of drying is being eliminated, and the coal is not pulverized so finely as was thought necessary in the past. This tendency, which has been made possible by better furnace and burner design is reducing the cost of preparation of powdered coal. In this connection, attention is again called to the results of tests given in Table I. The second vertical column gives the average of three tests made with undried coal, and the third column the average of the results of the two tests with coarse coal. These two groups of tests show that complete combustion was obtained with as low excess air with the coarse coal and the undried coal, as with the dried and more finely pulverized coal of the first group of tests.

It is the belief of the authors of this paper that the near future will see a greater reduction in the cost of preparation, due both to the improvement in pulverizing machinery and the ability of furnaces to burn coarse and undried coal. The reduction in the cost of preparation will stimulate the use of powdered coal.

It may be pointed out in conclusion that the higher the price paid for coal and the lower the cost of electricity, the greater are the advantages to be derived from pulverizing coal before burning it. Pulp and paper manufacturers, situated as they commonly are, far from coal-mines and near to water-power, may therefore hope to derive more benefit from burning powdered coal than will those who generate steam with cheaper coal, but whose electric power for preparing the coal costs considerably more.

DISCUSSION

Mr. J. C. Hobbs, *Chairman*:* Mr. Kreisinger has covered a lot of ground, but it would be impossible to cover such a subject completely in so short a time, so there must be some questions which you wish to ask. I will start by asking Mr. Kreisinger if the St. Joseph Company tests were not made without a water screen, and if this was not in part responsible for the lower efficiency than that obtained at Milwaukee.

Mr. Henry Kreisinger: The last tests were made without water screen and for that reason the CO_2 was rather low.

Mr. L. W. Marso:† Referring to the first side in which the speaker showed a series of tests, as I remember it the moisture in the first one was 2.75 per cent., in the second about eight per cent. and in the third about three per cent. I have seen some data obtained at the Ford Motor Company's plant where they are operating without driers and, as I understand it, they find that up to three per cent. moisture, or about one per cent. contained and two per cent. surface moisture, the loss of energy is comparatively small—between one and three kilowatts. From three to five per cent. however, the power consumption increases 25 per cent. and the production of the pulverizer drops off considerably.

In the second slide, he showed the setting of a boiler furnace at the Oneida Street station of the Milwaukee Electric Company. In explaining the operation of a setting of that type he said that about 15 per cent. of the air came in the burner and about 85 per cent. was supplied through the openings in the furnace walls. In connection with that I would like to read an extract from the report of an engineer who investigated the Milwaukee installation a couple of weeks ago.

"At the Oneida Street plant the operating crew on a month's run ran

*Assistant to Superintendent of Power Stations, Duquesne Light Co., Pittsburgh.

†The Hardinge Company, New York.

the boilers at a fraction over 80% efficiency with an average of 15% CO_2. The settings have been altered so that the combustion air is preheated by passage through ducts in side walls and bottom and all introduced with the coal except that induced through the ash pit door. The openings in front wall of setting have been permanently closed."

I would like to know if that report is correct, and if these tests were run before or after the above changes were made.

MR. HENRY KREISINGER: First is the question of moisture. It is unfortunate that we call all the water that is in the coal, moisture. It might be more convenient to call "moisture," the part of water that is in the coal without making it appear wet; and "wetness," that part of water which is on the surface and makes the coal look and feel wet. It is the surface moisture or the wetness that causes the coal to stick together and give trouble in conveying and feeding. Eastern coal may come out of the mine with 1½ per cent. moisture, and, if another 2½ per cent. of moisture is added to it, the coal will appear wet and stick to the fingers when we touch it. Such coal will give trouble although it contains only four per cent. moisture. Illinois coal with eight per cent. moisture may appear dry, and pulverize and handle easily, so when we know just the percentage of moisture, without knowing other characteristics of coal, it is difficult to tell whether or not the coal will give trouble on account of the moisture.

As to the second question—that at the Oneida Street station all the air is introduced with the coal, and the openings in the front wall are closed—I would say that if the engineer mentioned could have gone inside of the furnace, he would have seen that the air openings in the inside wall were open. The air passed through the hollow walls and entered the furnace through the openings in the inner wall. Had the openings in the outside wall been open, the air would have flowed from the outside directly into the furnace without flowing through the hollow walls. This is the reason why the openings in the outside wall were closed.

The tests referred to in this paper were made before the furnaces were changed to hollow-wall construction.

Mr. J. R. Mason:* I would like to ask what is the real purpose of the larger furnace. Last Saturday evening some of us listened to a number of combustion experts, and the gist of all the talk was that furnaces were made higher and larger for the purpose of helping to complete the combustion. From some of the literature printed on this question we are led to believe that, if the proper amount of air is allowed to penetrate the combustible gas, combustion occurs immediately and if a furnace is made longer it will help the combustion as well as to make it higher. Is it necessary to enlarge the furnace to take care of the larger amount of gas? For instance, if at normal rating you would use 2000 pounds of coal per hour and then increase to 5000 pounds per hour or 250 per cent. rating, would you not need a larger furnace for that purpose as well?

Mr. Henry Kreisinger: The real purpose of the large furnace is to get nearly complete combustion with low excess air. Powdered coal has to stay in the combustion space for about two seconds to be completely burned. It burns while it is in suspension in the combustion space, and in order to keep it at least two seconds in the furnace, we have to make the furnace very large. The experts who say that the combustion is instantaneous if the gases are properly mixed with the air, may be right but as yet we cannot get the proper mixture. We have to have a large furnace until we find out how to burn the coal in a small one. The coal travels through the furnace at a high speed and in order to keep it in there at least two seconds, we have to make the path very long. If we were to reduce the space, the coal would pass out of the furnace before being completely burned.

We are probably impressed with the large size of the combustion space in powdered coal furnaces, because we are accustomed to see small stoker furnaces; but the stoker furnaces are much smaller than they ought to be. The stoker furnaces that were built ten years ago were much too small. The boilers were set with the front head six or seven feet above the floor. When the stoker man came, he could not get the stoker under the boiler

*District Sales Manager, Wickes Boiler Co., Pittsburgh.

and get a furnace of sufficient combustion space to get good results. In modern practice, the front boiler header is set as much as 18 feet above the boiler-room floor for stoker furnaces. That gives a furnace nearly as big as the furnace designed to burn powdered coal.

Mr. J. R. Mason: That brings up to me the question of high velocity gas, and I believe Mr. Kreisinger, when he was associated with Mr. Ray, was the first to make experiments along that line. In the transfer of heat there are three elements to be considered. First, the temperature difference between the gas and water side of the heating surface; second, the amount of heating surface exposed; third, the time of exposure. To my mind there is a limit to velocity. I do not believe you will go very far before you reach the limit. I would like to know if Mr. Kreisinger has anything on that question as to what he thinks the limit to high velocity is, or any idea how far you have to go before you interfere with the other laws that govern the transfer of heat.

Mr. Henry Kreisinger: The furnace should be designed large enough for the highest rate of combustion; that is, in the case mentioned by Mr. Mason, the furnace should be designed for burning 5000 pounds of coal per hour. Such a furnace would burn coal at the rate of 2000 pounds per hour with good efficiency. Of course, the air supply must be under perfect control so that the right amount of air is admitted into the furnace for any desired rate of combustion between the two limits. At the rate of combustion of 2000 pounds per hour, such a furnace could be operated with 16 per cent. of CO_2 in the flue-gases. With the rate of combustion increased to 5000 pounds of coal per hour, the furnace could be operated with about 14 per cent. CO_2.

With most boilers, the rate of heat transfer is almost directly proportional to the velocity of the gases passing through the boilers; thus, at 125 per cent. of the boiler rating, the gases leaving the boiler will be cooled down to about 450 degrees F. When the rating is increased to 250 per cent. the gases will leave the boiler at a temperature of about 525 degrees F. Thus, while the rate of heat absorption is doubled, the efficiency decreases only

about two or three per cent. So far, we have not reached the limit of the rate of heat absorption by water-tube boilers. In the past, the limiting feature was the size of the furnace; or, rather, the inability of the furnace to generate heat at high rates. There are many boilers now being operated at 300 per cent. rating and the time is not far away when 500 per cent. ratings will not be anything uncommon. When we made such statements 15 years ago, we were considered impractical dreamers.

MR. A. E. BLAKE:* What is your opinion as to the utilization of fine coke or fine waste coal from anthracite in such a system as the paper describes?

MR. HENRY KREISINGER: I do not know much about burning anthracite in powdered form. I understand it can be burned but it is hard on the pulverizing mill.

MR. A. E. BLAKE: I have a few ideas to present which I hope the powdered coal enthusiasts will kindly tolerate, for I believe that what I want to point out ought to have mention whenever the use of bituminous coal is under discussion.

I think the failing supply of cheap natural gas has been chiefly responsible for the onset of powdered coal as a fuel for various purposes, and, while volumes could be said by way of comparison of these two fuels, pro and con, I think that the final outcome will see powdered coal in a position warranted by its merits only; but the rush to this fuel would remind one of the rush which always occurs to install any promising feature for industrial work.

Beyond all doubt powdered coal has become an extremely satisfactory boiler fuel, and some headway is also being made in the line of industrial furnace heating. The fact that the source of heat supply is cheap, however, ought not to be mentioned as a reason for refusal to consider proposals for increased economy, or for substituting other means for securing energy. With the exception of a few Government experts and so-called theorists,

*Pittsburgh Representative, U. G. I. Contracting Co., Pittsburgh.

there seem to be a very few people who take proper thought of natural resources and their conservation, especially in relation to the coal supply.

Statistics tell us that in 1918, 48,000,000 tons of coal were carbonized in bee-hive ovens. In this case the volatile portion of the coal is utterly wasted. The use of by-product ovens would have saved 12,000,000 tons of this, or 28 per cent.

In the utilization of bituminous coal for power purposes, one of its chief uses, the volatile combustible matter serves as a fuel, and only the fixed nitrogen is a dead loss. It is rather comforting to find that such subjects as these are being considered in various connections in Congress, and I think you will all be interested in the following quotation from the *Congressional Record* for Feb. 25, 1920, giving some remarks which were made relative to the tariff by the late Senator P. C. Knox:

"Why was Germany in the position that her chemists have achieved much more than the chemists of this or any other country? The simple fact is that in Germany they do not burn their coal; they roast it. They make coke as a fuel, and they utilize their by-products for their chemical purposes, and especially for the manufacture of dyes. In Germany there is not a single bee-hive oven. A bee-hive oven is the old fashioned oven in which the coke is burned, and the gases and the smoke escape into the atmosphere. In the United States probably not more than half of the coke that is manufactured is manufactured in the by-product oven that is used exclusively in Germany. I would amaze you if I were to read to you the value of the by-products which pass off from these bee-hive ovens in the United States and pass up the smokestacks of the factories, where the gases and the other by-products are not utilized.

I have here a table taken from the testimony that was given before the committee, which shows the total amount absolutely wasted in the course of a year to be in value $930,188,000. It is given by States, and if there is any Senator who is curious to know the loss in his own State, I shall be only too glad to read it. Referring to the State of Utah, for instance, the loss there is $9,999,000. It runs from four to eight and ten million dollars in the various States, up to the State of Pennsylvania, where the loss is $329,000,000 per annum.

Although the products of destructive distillation vary within wide limits, yet the following table may serve to give an approximate idea of what may be gotten from a ton of soft coal.

From 1 ton of soft coal you get 12,000 cubic feet of gas; liquor (washings), ammonium sulphate, 7 to 25 pounds; tar, 120 pounds, from which when redistilled we get benzene, 10 to 20 pounds; toluene, 3 pounds, xylene, 1½ pounds; phenol, one-half pound; naphthalene, three-eighths of a pound; anthracene, one-fourth pound; pitch, 80 pounds; and coke, 1200 to 1500 pounds.

While those are the products of a ton of coal, and there are only 8 or 10 of them in number, yet the chemists will make tens of thousands

of articles out of these products by the synthetic process. They make the explosives that kill, and they make the medicines that cure. * * * *

Mr. President, if this measure were a project to invest a billion dollars of Government money for the purpose of building up an industry that would save a billion dollars a year and be a great factor in our preparedness against another destructive war, I would favor it; but it is not that. The gentlemen who propose to build up these industries propose to do it at their own expense, and all that they ask the Government of the United States to do is to prevent for a period of three years the importation into this country of such dyes as are made here in merchantable quantities. The proposition is reasonable. It has nothing to do with the tariff. It is not a question of tariff legislation. It is a question of wise, farseeing preparedness and of wise, farseeing economy."

It seems as if little more needs to be said to convey to you my line of thought, but there is one more item which serves to show what one other country has to deal with.

In *Chemical and Metallurgical Engineering* for Nov. 24, 1920, page 1033, there is an article which describes the use of low-grade coal. I will quote a little from it:

"In order to utilize this slack and mine waste, which is a coking fuel containing 42 to 45 per cent of moderately fusible ash and 18 to 20 per cent of volatile matter, the Société des Mines de Montrambert has had recourse to gasification, dividing the operation into two parts. The coal is first charged into coke ovens, the byproducts being recuperated and the waste heat employed for steam generation; the coke thus formed is next utilized in gas producers and the gas produced is employed in two internal combustion engines for generation of electrical power.

By this method are avoided the difficulties resulting from a direct treatment in producers of a coking coal, rich in viscous tar and which produces continuously, through agglomeration, compact masses of clinker in the producer and gives off a gas whose purification is extremely difficult. These low grades of coal can be handled very well in coke ovens and the use of coke in the producers permits an exact regulation of the latter, making it possible to produce a gas which is practically constant in composition and calorific value.

Since this gas is to be used in internal combustion engines its purification is necessary; but the Société des Mines de Montrambert considers that even if the gas were destined for industrial furnaces or boilers it would be worth while in most cases to purify it to a certain extent and to recover, as far as possible, the condensable byproducts and the sensible heat carried by it.

Its installation of two 10-ft. rotating grate producers is therefore completed by purifying and cooling apparatus which insures the deposit of the dust and tar contained by the gas, and which cools and so dries it, preheating the air blast for the producers at the same time. In this same apparatus the hot air is saturated with water and the proportion between the weights of water vapor and air furnished to the producer is easily controlled by regulating the temperature of the air.

The gas after its passage through this apparatus is discharged by an extractor into a series of purifying cases and finally passes to a holder from which it is drawn by the suction of the gas engines.

A supplementary installation is added to the equipment mentioned above

for the recuperation of the nitrogen content in the coke, of which about 70 per cent is recovered in the form of ammonia salts. The further recovery of sulphur compounds and other products is being studied.

The works has been in normal operation for about two years, furnishing a monthly production of 200,000 kw.-hr. which is utilized by the Société des Mines de Montrambert or discharged upon the system of the local electric company. Its operation has been so successful that the Société de Montrambert is at present considering the construction of a large works comprising coke ovens and producers capable of handling all the low-grade coal and non-salable waste produced by its various mines. It was as part of this project that this company decided in 1919 to experiment upon the use of the available producer gas for the firing of boilers in order to determine whether this gas was suitable under practical conditions for such an application and also to find out what efficiency could be expected of a boiler so fired and whether it would be advantageous to provide batteries of boilers supplying turbo-generator groups instead of internal combustion motors."

The producer gas made from coke having 45 per cent. ash, averaged 96 B.t.u. per cubic foot, and its utilization for steam raising showed an efficiency of 73 per cent.

In view of the pains taken abroad with fuels which we would consider waste material, and which form many of the burning mine dumps in this region, I would argue that we owe it to our descendants to omit no reasonable measures to prolong the life of the coal supply, at least whenever means can be found to do so, on the basis that a fair return on the investment is possible. This French company is practising complete gasification with by-product recovery, even to the *n*th power, and is furnishing an example which we ought not to fail to observe, in view of the wonderful possibilities which exist in the application of that practice to our fine supply of bituminous coal.

Mr. Joseph Breslove:* Without any reflection on Mr. Kreisinger I may be able to answer Mr. Blake's question as to experts. "An expert" you know "is just an ordinary man away from home."

Anthracite is used in pulverized form under boilers at the M. A. Hanna plant near Easton, Pa. I was there two years ago and saw them burning pulverized anthracite under B. & W. boilers, using a nozzle something like Mr. Kreisinger showed, only wider, the sheet of pulverized coal coming out fan shaped

*Consulting Engineer, Pittsburgh.

and like a sheet of paper. The great difficulty was not in the furnace but in the wear and tear of the grinding machinery.

I would like to ask a few questions relating to the Milwaukee plant. What is the height of the stack on these boilers? How long does it take to bring up a cold furnace to normal rating, and to 200 per cent. rating? How often do they use the soot blowers? What percentage of ash goes up the stack and what percentage remains in the bottom of the furnace? In that particular type of furnace there is an air space between the outer and inner walls, the inner wall running a temperature of 1500 or 2000 degrees F. and the outer one possibly 100 degrees, or less. How do you keep that outer wall from cracking? That may sound easy but we have experienced some difficulty in this particular under similar conditions.

It may be interesting for you to know that we are just completing a pulverized coal plant in connection with a 470-horse-power boiler at Herrs Island. An investigation of powdered coal over a couple of years leads me to the conclusion that the size of the furnace is practically determined by the rating you are going to carry. For metallurgical furnaces, fine grinding is absolutely essential on account of the effect on the product; but, under boilers, fine grinding is not so essential, the fineness varying inversely with the size of the furnace. Apparently Mr. Kreisinger's experiments have demonstrated this to be the case.

When it comes to drying it is more a matter of distributing the coal than burning it. The coal, when ground in a central plant and distributed to overhead bins, must not contain too much moisture or it will cake in the feeders and not flow uniformly. In order to obviate the necessity of using a cooling medium at the bottom of the furnace at Herrs Island there is a drop of 28 feet from the arch to the floor. When running at about 200 per cent. rating it has been demonstrated that the ash will deposit on the bottom in a granular form and without slagging, with this depth of furnace.

Mr. Henry Kreisinger: The height of the stacks of both plants is about 200 feet. It will take about 45 minutes to bring up a cold furnace and boiler to 200 per cent. rating. As to the

ash, about 25 per cent. is deposited at the bottom; about 20 per cent. is deposited in the space between the second and third pass; about 15 to 20 per cent. may be deposited in the economizer chamber; 10 per cent. may be deposited on the floor of the main flue; and 15 to 30 per cent. is carried out the stack. It all depends on how long the passage from the boiler to the top of the stack is. The ash is dropping out of the gases the whole length of the gas passage.

As to the cracking of the wall, it may be said that at the Milwaukee plants the lining is entirely separate from the outer wall. The two walls are connected with butt-joints and can move entirely independently of each other.

The soot blowers are operated every four to eight hours. It is preferable to blow the flues oftener and for a shorter period. I would say that with the revolving soot blowers, 30 seconds to a section is sufficient. Often steam is wasted in blowing the flues too long. After the first 30 seconds of blowing there is very little dust left in the flues and there is no need of wasting any more steam. The dust from pulverized coal consists of small beads which are spherical. The particles of ash melt going through the furnace, and the surface tension of the liquid converts them into spheres. When these spheres go through the boiler, they are cooled and frozen to solid beads. The beads can be seen very plainly through a microscope.

As to obviating the necessity of using a cooling medium at the bottom of the furnace by making a deep furnace, that, I consider a delusion. If the furnace is operated at high ratings with low excess air for a long time, the bottom of the furnace will get hot no matter how deep the furnace is. If the ash fuses at a low temperature, there will be a lake of slag at the bottom of the furnace.

Mr. H. C. Cronemeyer:* I would like to ask as to the length of the pass of the powdered coal through the furnace. In the second slide I noticed the burner was not so far distant from the lower bank of tubes; but I suppose the powered coal travels towards the bottom of the furnace and then rises again. How is

*Designer, Jones & Laughlin Steel Co., Woodlawn, Pa.

that controlled? I presume it would take a rather nice judgment in adjusting the draft and the speed of the coal coming into the furnace; otherwise there would be a short swing of the powdered coal right up among the tubes. How is that controlled?

Mr. Henry Kreisinger: The depth to which the flame descends into the furnace depends entirely upon the pressure of air supplied with the coal. The higher the air pressure at the feeders, the lower the coal descends into the furnace. At the Oneida Street plant, the furnaces are 12 feet deep below the arch. The air pressure at the feeders is six to seven inches of water, and the flame descends to within two or three feet of the bottom. At the Lakeside station, the furnaces are 22 feet deep below the arch. The pressure of the air at the feeders is 10 to 12 inches of water and the flame descends to within three feet of the bottom. In other words, air pressure of one inch of water, forces the flame down about 1½ feet. The adjustment of the depth of the flame is comparatively an easy matter.

Mr. F. F. Espenschied:* I would like to ask what is the limit of rating secured in these furnaces and what maximum rating you did obtain; also, are you troubled with clinker forming on the lower row of tubes, such as so frequently occurs with the stoker; also, what is the height of setting necessary for mixing the gases and burning them? I believe that powdered coal and stokers demand the same conditions—namely, sufficient time and space for proper air and gas mixing. What is the pressure drop between the furnace and the boiler room? There must be some drop through those preheating ducts you mentioned, necessitating additional stack draft or induced draft.

Mr. Henry Kreisinger: The limit of rating on these types of furnace may be defined as the maximum weight of coal that can be burned per hour with a completeness of combustion of at least 98 per cent. and about 30 per cent. excess air. If the com-

*Pittsburgh District Representative, Commercial Truck Co., Pittsburgh.

pleteness of combustion is less than 98 per cent., or if the excess air is more than 30 per cent., the results are too close to those obtained with good mechanical stokers, and the powdered coal begins to lose its advantage of high efficiency. In other words, a good mechanical stoker leaves a certain narrow margin of high efficiency within which the powdered coal must stay in order to justify the cost of its preparation.

In order that completeness of combustion of at least 98 per cent. with an excess air less than 30 per cent. may be obtained, the maximum rate of combustion of powdered coal should be limited to two pounds of 12,500 B.t.u. coal per cubic foot of effective combustion space per hour; or, making this statement independent of the quality of the coal, the maximum rate of heat generation is about 25,000 B.t.u. per cubic foot of combustion space per hour. This is true with our present knowledge of the art of burning powdered coal. Maybe in future when we know more about this art, we shall be able to increase this maximum rate of combustion, but at present we have to adhere to what we know. It is frequently pointed out that in locomotives the rate of combustion far exceeds the above limit, but with hand- and stoker-fired locomotives, 10 to 20 per cent. of the coal fired leaves the stack in the form of cinders, making the efficiency of combustion as low as 80 per cent. This low efficiency of combustion with hand- and stoker-fired locomotives gives the powdered coal a much wider margin to work on, and consequently the rate of combustion of powdered coal can be much higher in locomotives than in central-station plants.

The coming of powdered coal has stirred the stoker furnace designer to a greater activity, with the results that modern stoker furnaces are much better designed than they were in the past. Some of the latest stoker installations have as large furnaces as are used in the powdered-coal installations, and, for this reason, very good combustion with low excess air is obtained.

The powdered-coal furnace gives trouble from slag deposit on the lowest row of boiler tubes when the rate of combustion is too high and the excess air too low. We know that this slag trouble is particularly bad in stoker installations with very low

setting; that is, where too much coal is burned per cubic foot of effective combustion space.

The pressure drop between the boiler room and the furnace is 0.05 to 0.25 of an inch of water at the top of the furnace, and 0.25 to 0.5 inch, at the bottom of the furnace. The furnace is high and is filled with gases at very high temperature and, therefore, there is a considerable stack effect in the furnace. At the top of the first pass in the boiler setting, there is frequently a slight pressure.

Reference has been made to mixing of gases. So far as we know at present, the mixing is the deciding factor in the rapidity of combustion. It is not a question of how much time it takes for a particle of carbon and oxygen to combine after they have been brought together, but how much time is required to bring them together. Combustion space is required mainly to bring the combustible and the free oxygen together. When the two are brought together, the combination is almost instantaneous. Our efforts in future will be directed towards bringing the combustible and the oxygen together quickly. That does not mean, however, that the problem will be solved by supplying all the air needed for combustion with the powdered coal. Although the particles of powdered coal are very small, the combustible in them is very concentrated as compared with the concentration of oxygen in the air. At the furnace temperature, the volume of air required for the complete combustion is 5000 to 8000 times as large as the coal particles themselves. If all the air were supplied with the coal, time would be required to bring the oxygen within this volume to the surface of the coal particles, and to move the products of combustion away from the surface. Much better results can be obtained by moving the coal particles through the air than with the air. By bringing the coal particles into the furnace at high velocity in one direction and the air at low velocity in another direction, the particles of coal are brought quickly in contact with free oxygen and the products of combustion are scrubbed away from its surface.

Mr. J. C. Hobbs, *Chairman*: What are the effects of baffle

arrangement and boiler pass design on the tendency to slag the lower tubes?

MR. HENRY KREISINGER: The larger the opening into the first pass, the less will be the trouble with the incrustation on the tubes of the boiler; because as the gases carrying the small particles of coal ash enter into the first pass they have larger space to go through and they move more slowly; consequently, as the particles approach the tubes they are cooled by radiation below the sticky point, so that when they strike the surface they do not adhere to it. In making designs for a boiler, it is advisable to make the first pass as large as possible in order to reduce the velocity of the gases entering the first pass.

MR. C. D. READ:* In that slide showing the boiler settings of the Oneida Street plant there seemed to be a row of hollow tile. Does that materially affect the efficiency of the boiler setting and of the boiler?

MR. HENRY KREISINGER: The hollow tiles were put in some of the settings at the Lakeside plant to prevent radiation losses. The air space in the tiles was made part of the system of air-cooled walls. The tiles are no longer used because of their mechanical weakness.

MR. J. B. CRANE:† As to the burning of anthracite at the M. A. Hanna plant, the Lykens coal is semi-anthracite, containing seven per cent. volatile matter, while ordinary anthracite contains four to six per cent. In the Lykens field a large part of the coal comes out in finely powdered form, for which there is no market. They have a stock pile of 1,500,000 to 2,000,000 tons. They have a small briquetting plant but there is not enough market and it was in an endeavor to make a market for this fuel that they were led to experiment with pulverizing the coal at that time. The lowest volatile coal that had been burned in pulverized form up to that time contained 19 per cent. volatile.

The experiments with seven per cent. volatile coal were pretty successful. They then brought some coal from the culm piles

*Steam Inspector, Duquesne Light Co., Pittsburgh.
†Engineer, George T. Ladd Co., Pittsburgh.

in the larger anthracite field and ran a carload through the pulverizer, and that worked out pretty well—so well that they built a 4000-horse-power plant with the idea of using the anthracite from the culm piles. It worked fine for about two months and then the pulverizers commenced to go bad. They tried every kind of pulverizer they could find. They put in a 10,000-kilowatt plant in the Lykens district, using the semi-anthracite coal, and that was successful. In the other field they found a pulverizer that could grind that coal and they have been operating it quite successfully for the past few months.

On the by-product plant for using bituminous coal I had the fortune in 1918 to work on plans for a 200,000-kilowatt central-station and it was estimated that we could put in a by-product plant and, at the prices then prevailing for by-products, we could sell the coke and other by-products, and put the gas under the boiler, and pay 10 per cent. on the investment. The thing that acted against it was the fact that with 1200 men to operate the by-product plant, in case of labor trouble the central-station would be shut down. At that time powdered coal had not been burned successfully under any large boilers and we were hesitant about using it. At the present time with powdered coal as a stand-by in case of a strike, or when there was no market for by-products they could burn the coal in powdered form. Last year Arthur D. Little & Company, worked out such a plan for a central-station near one of the large cities in the East on the basis of selling gas to the gas company and burning the coke under the boilers, and they showed a slight saving over any other form of operation; but nothing has been done about it up to the present time.

Such estimates made at this time may be very far from correct as the supply of some of the by-products is limited and the price is high, but with the installation of a large plant using 3000 to 4000 tons of coal a day, the supply would greatly increase and the price would drop, and in many cases it would be necessary to work up a market for these by-products.

A discussion of this subject is now available in an advance copy of a publication of the National Electric Light Association.*

*Report of Prime Movers Committee, 1922, pp. 226-229.

Mr. G. C. Emmons:* Employing Mr. Kreisinger's figures, that 15 per cent. of the air is blown into the furnace and the balance of 85 per cent. of the air for combustion is induced by the furnace draft; if we consider that these percentages are obtained when the boiler is being driven at 300 per cent. of rating and the rating is then reduced to 100 per cent. and the furnace draft restored automatically or otherwise to the same value that obtained 300 per cent. of rating, the same amount of air will continue to be induced. If the primary air is reduced automatically or otherwise to one-third of the quantity blown into the furnace at 300 per cent. of rating, the total air entering the furnace will be 270 per cent. of what it should be for 100 per cent. rating. If the damper is not actuated, the furnace draft will increase and the total air entering the furnace will be in excess of 270 per cent. of what it should be for 100 per cent. rating.

It therefore strikes me that one of the very great problems in pulverized coal firing for boilers, when the greater part of the air for combustion is induced by the furnace draft, is draft regulation.

Mr. Henry Kreisinger: The flow of air into the furnace is controlled by the draft. When the furnace operator turns on more coal, he also turns on more draft and keeps the two together just as it is done in a stoker plant. When more steam is needed, the stoker is speeded up and the draft is increased.

Mr. G. C. Emmons: Is it automatic?

Mr. Henry Kreisinger: No, but it can be made automatic, and there is a chance for some inventer. Powdered coal lends itself to regulation better than any other method of burning coal. In the last chart, I showed that when the load varied from 100 to 200 per cent., the amount of CO_2 was maintained very close to 14 per cent. That was the fireman's job and he was supposed to regulate the draft and the feed.

*Steam and Efficiency Engineer, Republic Iron & Steel Co., Youngstown, O.

Mr. H. R. Thayer:* I would like to ask if the speaker can tell us what is the relative rating of boilers burning ordinary coal and powdered coal, and for an average fuel about what is the cost per ton to prepare the coal in powdered form.

Mr. Henry Kreisinger: The rating that can be developed by different methods of burning coal—stoker, hand-fired, or powdered coal—depends on the size of the furnace. The larger the furnace, the higher the rating that can be obtained with the boiler. This statement holds with powdered coal as well as with the stoker-fired furnace.

Mr. M. F. McConnell:† In the first chart shown by Mr. Kreisinger, three tests were shown comparing three degrees of fineness of the powdered coal. I note that there is practically no difference in the efficiency over a range of fineness between 73 per cent. and 64 per cent. through a 200-mesh screen. I would like to know if any tests have been made to demonstrate how far we could go in the direction of coarser grinding before we would seriously affect the efficiency.

Mr. Henry Kreisinger: We have not gone far enough with our investigations to determine this limit. We know we can pulverize the coal to a fineness of only 65 per cent. through a 200-mesh screen and get good results. Apparently, from 85 to 65 per cent. through a 200-mesh we are working on a flat curve. How far that curve is a flat line we do not know. That is still to be determined.

Mr. F. J. Crolius:‡ Have you found an appreciable reduction in the cost of pulverizing coal to 65 per cent. through a 200-mesh screen as compared with the cost of pulverizing to 85 per cent. to the same fineness; in other words, how much per ton is saved by the coarser grinding?

Mr. Henry Kreisinger: Undoubtedly we can increase

*Markhart-Thayer Engineering Co., Pittsburgh.
†Superintendent, Mingo Works, Carnegie Steel Co., Mingo Junction, O.
‡Steam Engineer, Homestead Works, Carnegie Steel Co., Munhall, Pa.

the capacity of the mill if we grind the coal coarser. We can grind seven tons with a six-ton mill so that the power per ton will come down and also the depreciation on the mill per ton is decreased.

Mr. J. C. Hobbs, *Chairman*: It is my understanding that the U. S. Bureau of Mines co-operated with the Combustion Engineering Company on this work. Mr. Blizard represented the Bureau, and is therefore in a position to give accurate information.

Mr. John Blizard: There is nothing that I can add to what Mr. Kreisinger has already said.

Mr. J. C. Hobbs, *Chairman*: Mr. Paul, have you anything to add?

Mr. J. W. Paul:* My investigations in pulverized coal have been made in connection with a study of explosions in coal-mines, and the results obtained do not have any direct relation to the subject matter discussed other than to show that the degree of dryness is a factor in the ease with which the dust may be inflamed when blown into the air; and that the propagation of the flame is influenced by the total inert material present in the form of moisture and ash.

The only question I have is this—what is the limitation in the ash content of pulverized bituminous coal for use in furnace work?

Mr. Henry Kreisinger: I cannot give you a definite answer to that. I have not yet been able to establish any limits. I don't know whether there are any.

Mr. J. C. Hobbs, *Chairman*: Are there any other questions? If not, we will close the discussion. Mr. Kreisinger, on behalf of the Society I thank you very much for coming here

*Chief, Coal Mining Investigations, Pittsburgh Experiment Station, U. S. Bureau of Mines.

and presenting the data and information you have given us. We felt that Pittsburgh deserved to have the best information on this subject, so we went to you for it.

Since this meeting marks the close of the fiscal year for the Mechanical Section, I take this opportunity to express my appreciation of the co-operation I have received from the members. It is my hope that you will give the incoming officers just as good co-operation as you gave to me—and a little better if possible. Sound engineering is without a doubt the foundation of Pittsburgh's industrial life, and upon you engineers rests the responsibility for the future of Pittsburgh. What you do next year, and during the years to come, will certainly determine the future of Pittsburgh. I thank you all.

FACTORS AFFECTING THE USE OF AIR IN OIL BURNING WITH COMPARISON OF COST

By W. C. Buell, Jr.*

INTRODUCTION

The question of the advantages to be found in burning liquid fuels with air under various pressures has been the subject of considerable discussion but little has been written on the subject, and figures of comparative performance are entirely lacking.

This subject is one of sufficient importance for a careful analytical discussion, as the summary at the end of this paper will show. As nearly every industry burns more or less oil or tar the subject is one of quite general interest, and a consideration of the summary of the analysis made hereafter will clearly show that it is possible to waste a large amount of money in purchasing a selected fuel or in using air that must be reduced in pressure to meet the requirements of combustion.

CLASSIFICATION

An examination of the oil burning systems offered for industrial heating practice will indicate that there are three general types of oil burners classified on a basis of air pressures at the source of supply from which they operate, and somewhat along the following lines:

1. Burners employing so-called "volume" air which is moved by high-speed fan blowers and delivered to the burners at pressures of from 4 to 10 or 12 ounces.

2. Burners operating on so-called "positive" air which is delivered to the burners by displacement or turbine-type machines and occasionally by high-speed centrifugal fans, at pressures of from 12 ounces to two pounds.

3. Burners utilizing "high-pressure" air which is delivered to the burners from compressor lines in which pressures ordinarily run from 50 to 60 or 100 pounds gage.

*President, Buell-Scheib-Mueller, Inc., Pittsburgh.

Each of the three foregoing systems has its advocates and it is usual for the manufacturer of oil burning equipment to follow the lines of least resistance when making recommendations and to propose equipment using the air pressure which is favored by the customer rather than to stand on sound engineering principles and to recommend equipment operating under the best economic conditions.

It is the writer's purpose to discuss at some length all of the factors affecting the use of air in oil burning under the above classifications, but with reference to the class of equipment included under 1, above, it should be understood that burners operating on the low pressures of this classification can not depend on the air to atomize the oil but must of necessity use a mechanical system, in which the oil fuel is atomized by the static oil pressure forcing the oil fuel through very small orifices in the form of a fine spray which the low-velocity air can easily pick up.

The use of this system is limited to oil which is very fluid and very clean; viscous or dirty oils will cause partial or complete cessation of operation and, with the necessity for the conservation of the petroleum resources of the country clearly before us, it is an unnecessary waste of the natural lubricating and potential chemical reserves of the country to use as fuel selected distillates of high Baumé gravity—the only kind which can be used successfully in the mechanical system as applied to furnace practice. As a matter of fact, in this day and age, only residual and heavy fuel oils should be considered as fuels.

A few manufacturers still offer "volume" systems. The more progressive propose the "positive" system, and quite a number advocate the use of "high-pressure" systems, while plant engineers are prone to specify that "100-pound air is available and will be used."

VELOCITY

Air Velocity at Various Pressures. A study of the dynamic head or velocity coming from the static air pressure when discharged against the atmosphere (which throughout this paper is assumed to be 14.7 pounds pressure, absolute, at 70 degrees F.) will show that at one inch water pressure the velocity will be 70

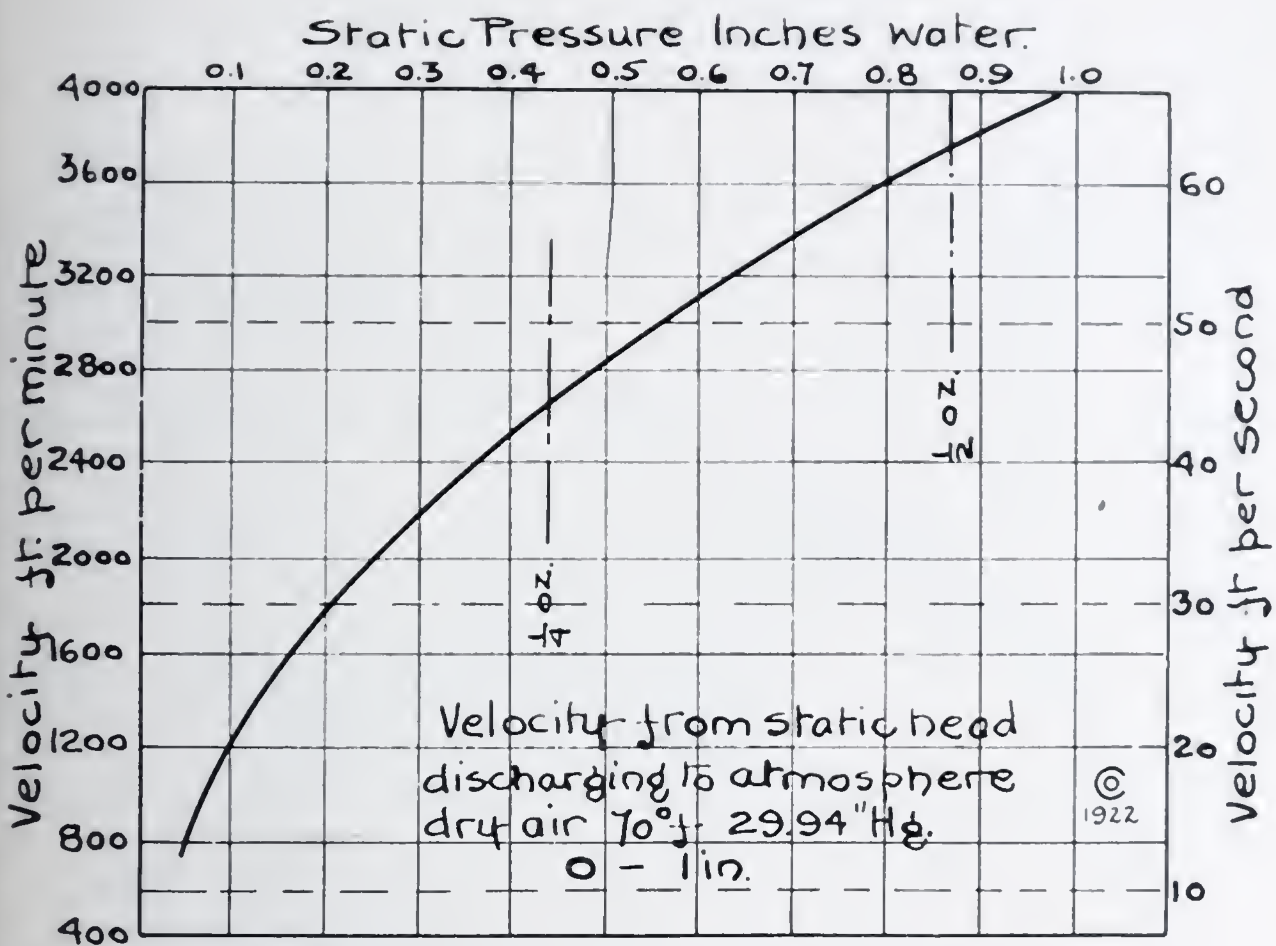


Fig. 1. Velocity of Air.

feet per second (Fig. 1); at one pound the velocity will be 352 feet per second, and at 4 pounds it will be over 700 feet per second (Fig. 2). If we calculate still further on the basis that four times the pressure will double the velocity, we will find that at 64 pounds gage pressure the velocity will be approximately 2800 feet per second. Of course, at the common 80 pounds gage pressure for compressed-air delivery the velocity will be still higher.

It must not be assumed that air passes into the burner setting at anything like the velocities which are a function of high-pressure air. Velocities are very much reduced by permitting the air to expand through the controlling valves, and the writer's opinion, based on observation, is that combustion can never be sustained when air enters the burner setting in excess of approximately 600 feet per second, which is the equivalent dynamic head coming from approximately three pounds gage static pressure. In ordinary combustion practice, velocities must not be greater than 100

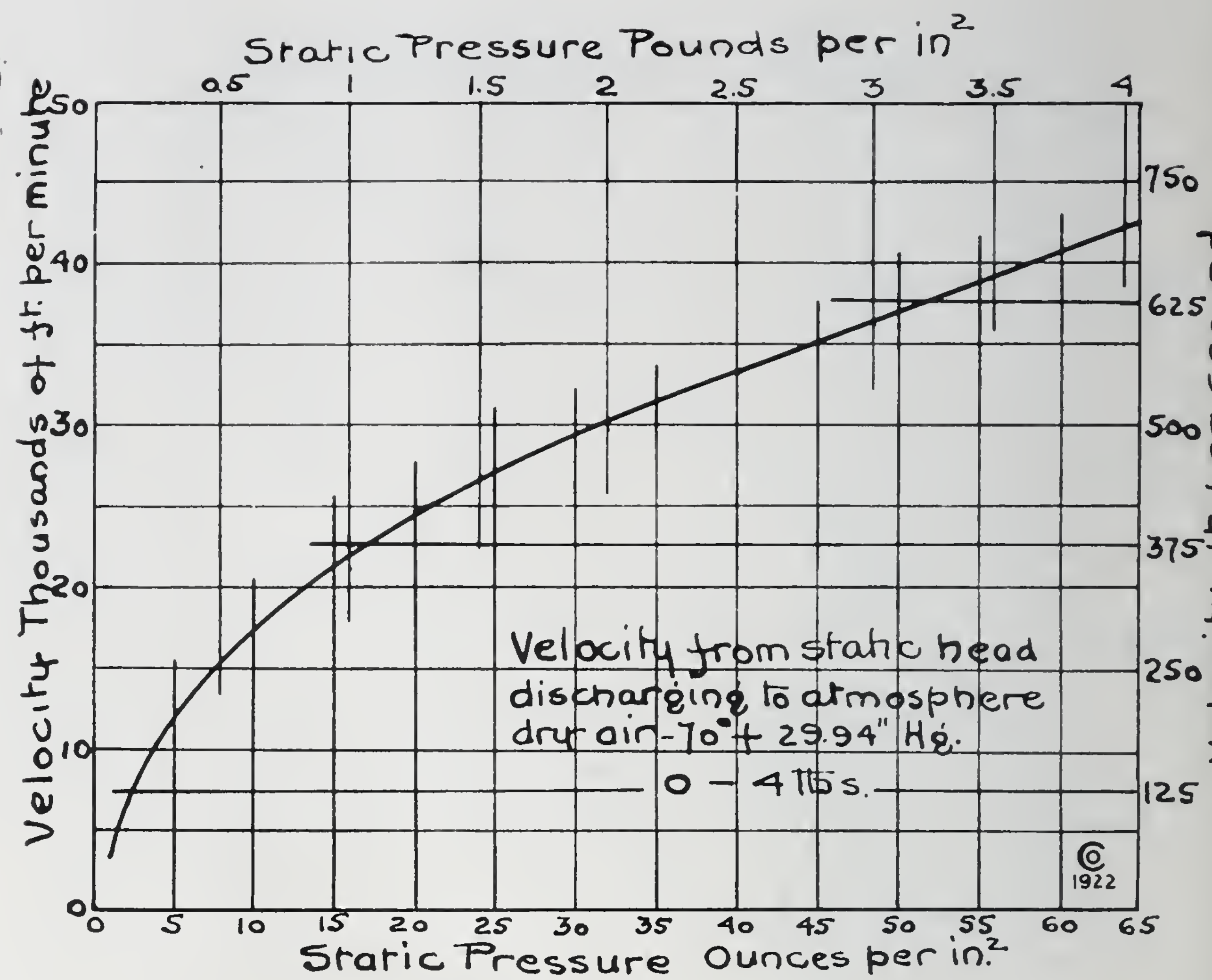


Fig. 2. Velocity of Air.

feet per second, six or eight inches ahead of the burner nozzle, if good results are to be secured.

It will be shown that the comparative cost of compressing air at two pounds, which produces an ideal combustion condition, is somewhat higher than the cost of compressing air initially to approximately 15 pounds gage, and, while air is seldom furnished by machines delivering it at an initial pressure of 15 pounds, the use of air initially compressed to 15 pounds offers interesting cost possibilities under certain installation conditions (see Table II).

Functions of Velocity. In oil burning practice, air velocity has two general functions: first, to atomize or shred the oil fuel into minute globules thus increasing the surface exposed to the volatilizing effect of the air stream and placing the oil in a gaseous or semi-gaseous form in order to burn it as rapidly as possible; and, second, to induce the greatest possible amount of atmospheric

air which may be secured through aspirator action in the throat of the setting and which may be frequently greatly increased by proper design of the setting and the burner.

Velocities for Atomizing. It will be conceded that in burning oil a certain standard practice must be established, based on good engineering principles, in order to secure the most satisfactory operation and this is especially true where it is desired to use the heavier grades of oil.

According to the writer's experience the general statement can be made that if oil reaches the burner tip at a viscosity of not more than 300 seconds on the Saybolt viscosimeter satisfactory atomizing will take place if the air column meets the oil at pressures of from 12 ounces to 15 pounds. The number of Saybolt seconds divided by 30 will give the ratio of fuel flow as compared to water and, therefore, 300 Saybolt seconds means that it is possible to use oil which is 10 times as viscous as water under equal conditions (temperature excepted); in other words, a volume of oil that requires 10 times as long as an equal volume of water to flow through a given orifice under similar conditions, will have a viscosity 10 times that of water.

Heating the oil is usual practice to reduce the viscosity of fuels that at ordinary temperatures are too viscous to atomize by air action. With all commercial oils offered for fuel to-day the viscosity of 300 Saybolt seconds will be secured at temperatures under 250 degrees F., and this seems to mark the maximum working limits of oil heating, as at higher temperature oils may to some extent decompose, possibly gasifying to some degree, and also have a tendency to deposit solid carbon; thus it may be safely said that 300 seconds Saybolt viscosity is the maximum limit allowable in oil burning. Therefore, in designing oil burning systems, the air system should be predicated for a fuel having a fluidity of 300 Saybolt seconds.

Velocity Found in Combustion. On this subject a number of assumptions must be made. Some research has been carried on, notably on pure hydrogen, to determine the rate of flame propagation and with air at atmospheric temperature and constant pressure it would seem that the speed of back fire of hydrogen is

approximately 14 feet per second. This means that, if hydrogen is mixed in proper proportion with a column of air having a velocity in excess of 14 feet per second, the air velocity will blow the point of combustion away from the point of mixing while if the velocity falls below the rate of 14 feet per second the hydrogen-air mixture will burn back to the point of mixing.

Little work has been done—or, at least, little has been published—on the subject of the rate of combustion of the hydrocarbons. Information is, at the best, unreliable and like the figures for hydrogen the results apply merely to laboratory practice. From such data as the writer has been able to collect and from observation in many years of combustion research work he believes that the speed of back fire in Pittsburgh natural gas is about eight feet per second with air in proper proportion and that in the case of fuel oil it is considerably lower and probably in the neighborhood of five feet per second; these results, of course, being found at constant pressure and atmospheric air temperatures.

Assuming the writer's figures to form a basis for consideration of the combustion of the commercial fuels, it may be stated that an air-oil mixture entering a cold combustion chamber with a speed in excess of five feet per second must be broken down to approximately that figure (at least) before combustion will be sustained.

A simple phenomenon which will illustrate this, is very frequently observed when endeavoring to light an air-oil mixture in a cold furnace. The air-oil mixture travels into the furnace perhaps several feet before combustion is sustained at all; but, as the combustion chamber heats up, radiant heat from the setting is focused on the entering air-oil column, and, as the mixture preheats, the point of combustion works back until combustion is sustained in proximity to the burner tip. As a further example it is quite often observed that, in order to sustain combustion at all in a cold furnace, a baffle brick must be placed a foot or so ahead of the burner so that the air-oil column may impinge thereon, reducing the velocity of a part of the column, at least, practically to zero. When starting, it is hard to maintain satisfactory combustion but as the baffle brick heats up, the heat of the brick supports the combustion of the air-oil mixture. A baffle brick

used as described is an indication of faulty conditions in the oil burner or the setting.

It must not be assumed that it will be desirable to introduce the air-oil mixture at a velocity as low as the speed of back fire. Excessively low velocities in the mixture, when the furnace is hot, have a tendency to make the resulting combustion altogether too "soft". As a matter of fact, it is customary to introduce the mixtures with a velocity of perhaps 60 to 80 feet per second, which, while it may make the lighting of a cold furnace somewhat troublesome, will permit a very excellent combustion condition. After a burner setting has become sufficiently heated to radiate heat to the air-oil column, and the air-oil column is heated beyond the ignition point of the mixture (which is relatively low and probably in the neighborhood of 700 degrees F.) combustion takes place and is readily sustained with velocities up to approximately 100 or 120 feet per second; these are, however, unduly high and usually produce the severe "blow-piping" action which causes rapid failure of the refractories on which the flame may impinge. It is only by preheating the air-oil column to a considerable degree that combustion is sustained with desirable velocities, which from the writer's observation appear to be about 65 feet per second. From the foregoing it will be seen that energy expended in compressing air to a point that will produce velocities much above 1000 feet per second is a considerable waste of money.

Reduction of Velocity. In oil burning practice, the velocity of the entering air must be broken down to the combustion speed equilibrium as quickly as possible, and at a predetermined distance from the burner tip in order to secure the liberation of the heat within the most desirable space. This is accomplished in several ways, singly or in combination, as follows.

The expenditure of dynamic energy in the mechanical air by atomizing or shredding the fuel is one means of reducing the velocity. The expenditure of energy in inducing atmospheric air is another. Friction in the metal funnel of the burner, and the fire-brick setting has a material reducing effect as does the expansion of air in the burner setting and the impingement of air-oil mixture on the surface of the brick-work. A sudden change of

direction of flow has a great reducing effect, but possibly the expansion of the air-oil column within the setting and the combustion chamber is the greatest single factor tending to reduce velocities, it being assumed that furnace pressures are but slightly above the atmosphere.

QUANTITY OF AIR REQUIRED FOR BURNING OIL

The amount of air required for combustion of fuel oil varies from 1250 cubic feet per gallon, in the case of a light oil approaching kerosene, to 1700 cubic feet per gallon with heavy oil approaching 10 degrees Baumé, or from 192 to 220 cubic feet per pound. Usually air in excess of that required for perfect combustion is present in the combustive reaction and excess air in itself is the source of one of the greatest fuel wastes. To a marked degree the use of excess air may be eliminated by proper engineering, the selection of the air mover, and the design of the air distributing system, the burners, and the setting.

In nearly every case, excepting only a few special heating operations, it may be assumed that perfect combustion produces the most desirable furnace atmosphere and anything that will assist in securing approximately perfect combustion will produce a saving of considerable magnitude.

It should be understood that perfect combustion is never accomplished commercially, except instantaneously, as there are many variables affecting the reaction which are continually acting to change the proportions of air and fuel; but excess air to the extent of 5 or 10 per cent. should mark a maximum in liquid-fuel practice, and this may easily be accomplished with a properly installed system.

INDUCTIVE PROPERTIES OF PRIMARY AIR AS APPLIED TO OIL BURNING PRACTICE

If the opening through the furnace wall through which the combustible mixture of oil and air passes, is correctly designed, and if the flues and other passages within the furnace are so proportioned that no undue pressure is set up within the furnace, a considerable amount of atmospheric air may be induced by the

action of the air from the mechanical compressor and thus the size of the blowing apparatus may be held relatively small.

In the case of "volume" air as defined in classification 1, page 201, the best conditions that may be secured average about two parts blower air to one part atmospheric air induced; or, in other words, for every 1000 cubic feet of air required for combustion, 650 cubic feet must be supplied by the blowers.

In the case of classification 2, or "positive" air, from 45 to 70 per cent. of all air required for combustion may be induced; or, for every 1000 cubic feet required, only 300 to 550 cubic feet need be supplied by mechanical means.

In the case of "high-pressure" air under classification 3, from 80 to 90 per cent. of the total may be induced; or, for each 1000 cubic feet required for combustion, but 100 to 200 cubic feet need be supplied from the compressor.

Fig. 3 shows a curve based on actual working figures which the writer has taken, and indicates what might reasonably be

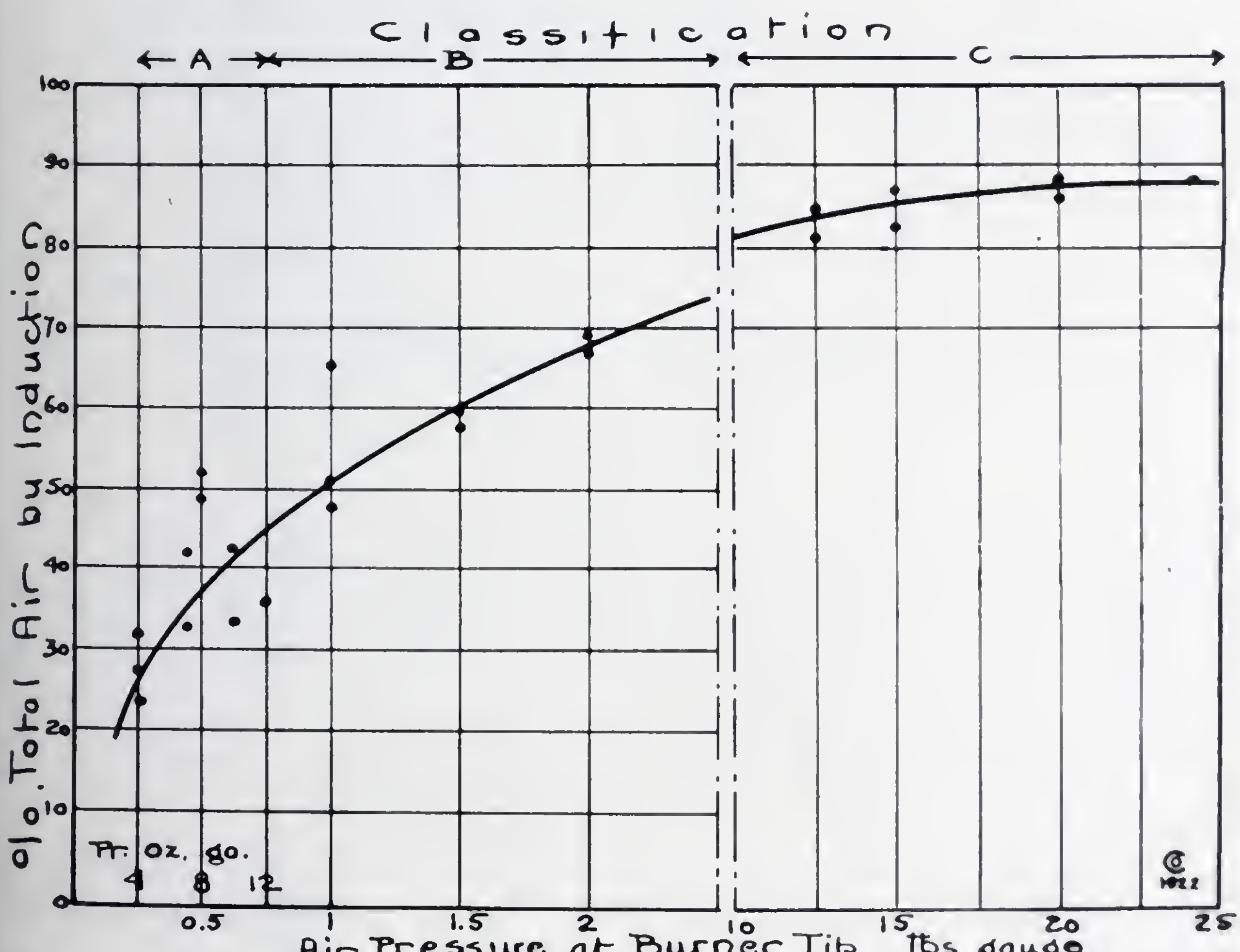


Fig. 3. Anticipated Air Induction with Properly Designed Throat and Low Furnace Pressure.

anticipated in percentage of induction with good furnace design. All of the results shown were obtained in the same furnace. The burner setting of this furnace is shown in Fig. 4, in which *A* is the oil burner; *B* the clamp holding the oil burner in position; *C* the funnel attached to the furnace wall; *D* a molded fire-brick block, conical in shape; *E* a deflector corbeled out from the fur-

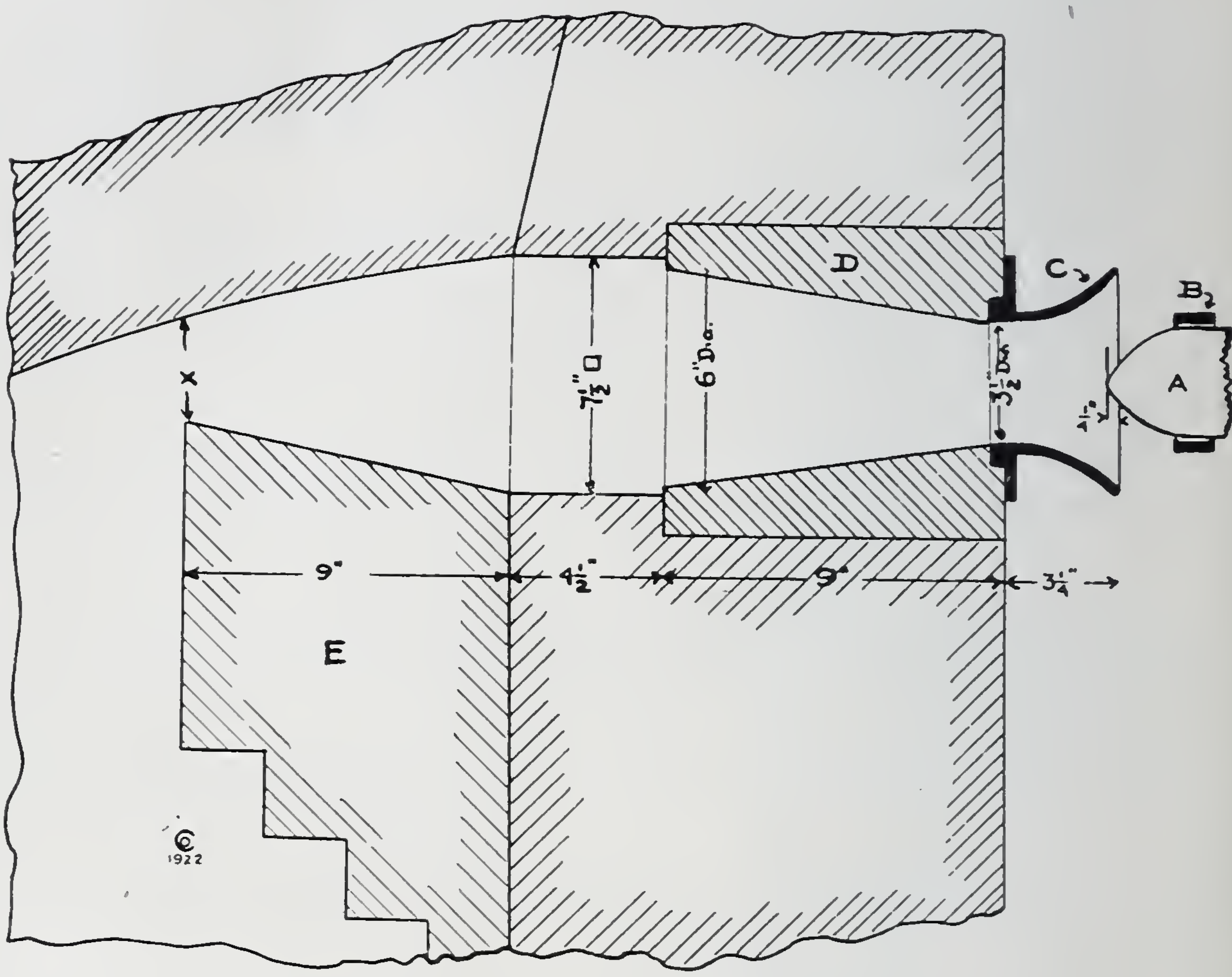


Fig. 4. Details of Oil Burner Setting.

nace wall and upon which part of the flame impinges. The width of *E* is only nine inches; it is open at the sides and the gas column is free to expand and pass to either side in addition to that part passing through the opening *X*. This setting is a very desirable type of setting for oil burning practice with an open-chamber furnace.

The furnace on which these trials were made, was fired by a single burner working against a flue area of 45 square inches, but dampered so that any desired pressure condition within the furnace could be developed. All results plotted in Fig. 3, were taken with the pressure in the furnace chamber less than 0.05 inch

of water. The experience is from six burners of different sizes and types.

It should be distinctly understood that the induction performance will vary with every furnace, and the chart should in any event be taken only as an approximation although it offers a very good medium from which to work.

COMPARISON OF BLOWERS

Table I notes some of the general operating characteristics of several types of air moving machines as ordinarily found in oil burning practice. Constant pressure and variable energy and volume are the desirable characteristics. From this table it will be seen that all machines have a characteristic of constant speed, excepting compressors which are assumed variable from the effect of the unloader.

TABLE I. COMPARATIVE CHARACTERISTICS OF AIR MACHINES

Type of machine	Delivery pressure	Operation	Speed	Volume	Energy	Pressure
Fan	4 to 12 ounces	quiet	constant	variable	variable	variable
Fan	¾ to 1 pound	hunming	constant	variable	variable	variable
Displacement	¾ to 2 pounds	noisy	constant	constant	constant	constant
Turbine	1 to 2 pounds	quiet	constant	variable	variable	constant
Compressor	15 pounds	quiet	variable	variable	variable	constant
Compressor	80 pounds	noisy	variable	variable	variable	constant

A change in volume produces a change in the energy characteristics of all machines except the displacement type in which type, however, volume actually remains constant by the "bleeding" of the air lines through a relief valve. A change of the discharge area affects the pressure of the fan-type blower only.

The turbo type machine for pressures of one to two pounds is probably the best type of machine for general use, for in this style of machine speed and pressure are constant while volume varies with the area of opening, and energy with the volume; thus, without change of pressure, energy varies with volume. This is also true of the piston compressor.

TABLE II. SUMMARY OF BLOWER PERFORMANCE FOR OIL BURNING AND COMPARATIVE COST

Machine type	Fan				Disp.	Turbine		Piston compressor					
Classification		A			B			C					
Stage	1	1	1	1	1	2	4	1	2	3	1	2	3
Delivery pressure	1 in.	4 oz.	8 oz.	12 oz.	1 lb.		2 lbs.	15 lbs.			80 lbs.		
Velocity, ft. per sec	70	176	248	305	352		496	1370			3157		
Atomizing properties	none	very small	small	good				good but max. limit			much too high for use		
Anticipated induction of atmospheric air, per cent.	less than 5	25	36	45	50		68	86			88		
Cubic feet of compressed air necessary to burn* 1 gal. fuel oil per min.	1500	1125	960	825	750		480	210			180		
Energy necessary to compress above volume of air, kilowatts	0.47	2.12	3.55	5.2	6.2		7.6	4.5	3.9	3.7	20.0	17.4	16.5
Power cost—air for 1000 gals. fuel, 2c. per kilowatt-hour	0.16	0.70	1.16	1.73	2.07		2.53	1.50	1.30	1.23	6.66	5.80	5.50
Approximate cost of blower and motor	....	$350	$350	$350	$625	$850	$1200	$1375	....	....	$1860	$2350	....

*Required 1500 cu. ft. of air per gallon of oil for complete combustion.

Table II shows that if a piston compressor is installed for oil burning developing initial pressures of 15 pounds gage there is a possibility of a considerable energy saving over any other type. However, in nearly every case where air from a piston compressor is used, the initial pressures are from 80 to 100 pounds and the operating costs are excessive.

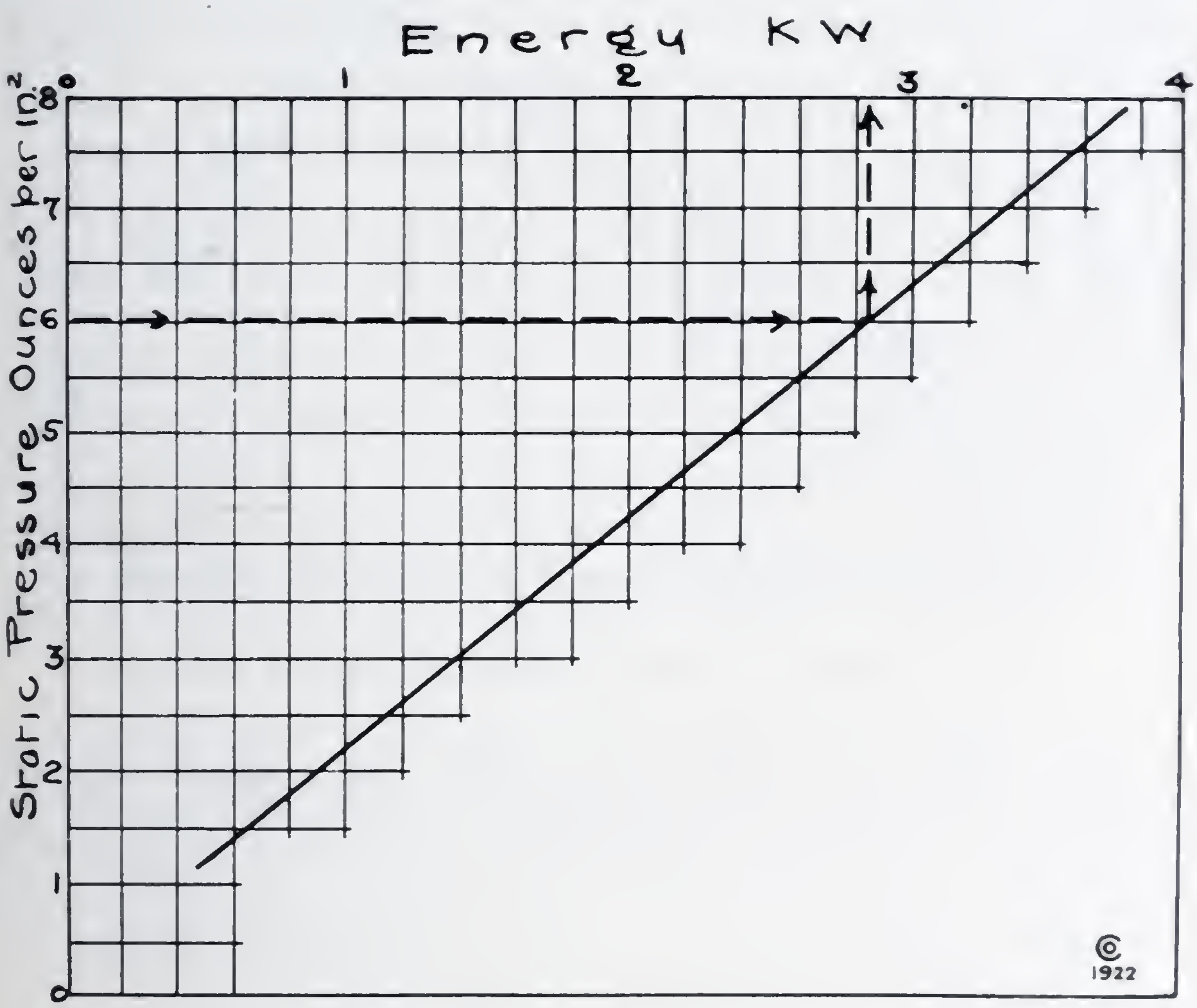


Fig. 5. Pressure-Energy Relations. Type P Blowers.

In Fig. 5 is plotted a composite curve of several blowers of one type, based on a constant delivery of 1000 cubic feet of free air per minute and showing to what extent energy varies with delivery pressure. This curve in common with the three following curves is taken from data published by manufacturers of the various types of machines. Accuracy of the results plotted in Fig. 5 is open to question as this shows energy and pressure as straight-line functions of each other, and this is incorrect. It is included, however, particularly with the idea of suggesting that printed tables of performance are not overly reliable.

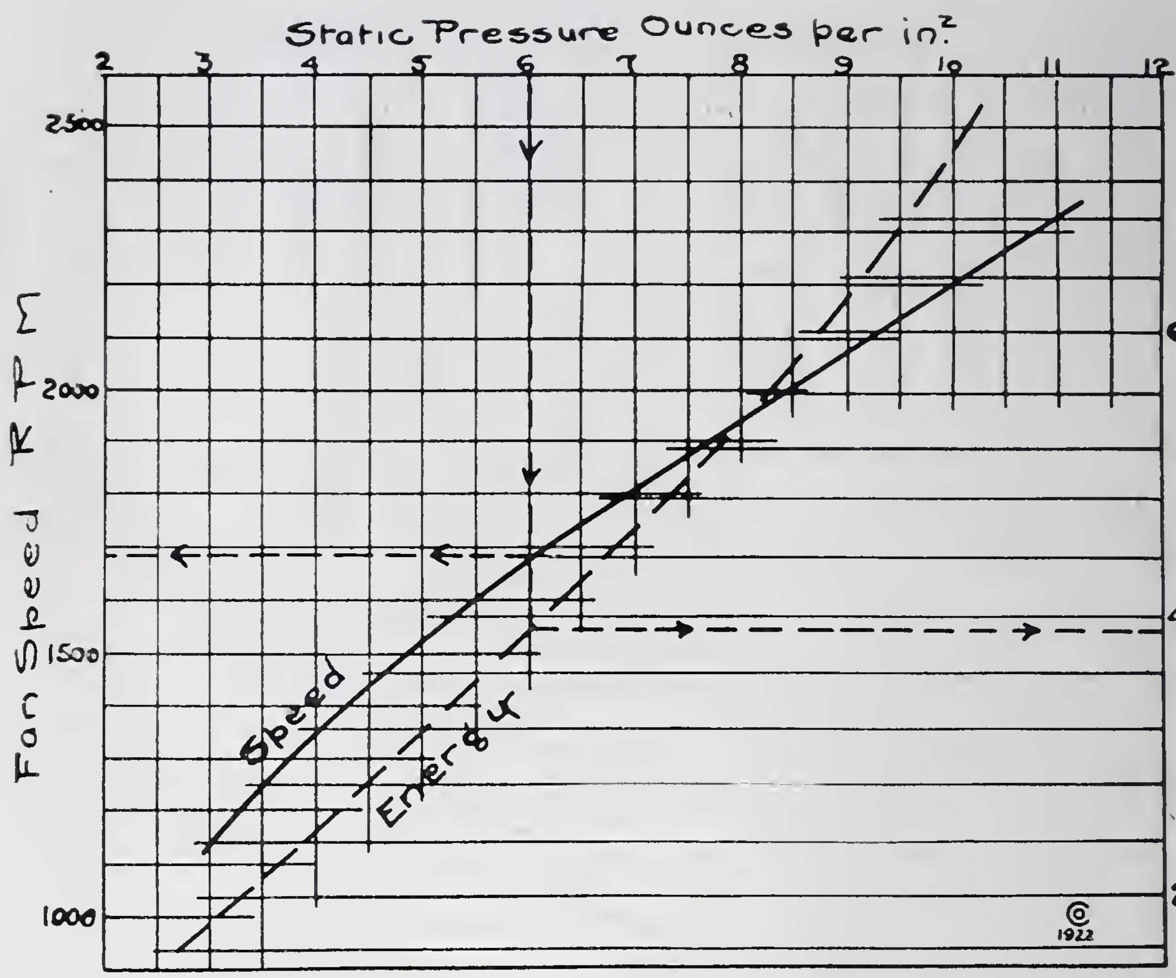


Fig. 6. Constant-Volume Performance of Fan Blower.

Fig. 6 gives pressure, energy, and speed characteristics of a fan blower of a different make, also operating at constant volume which in this case is 2000 cubic feet of free air per minute. The information may be taken as fairly reliable for machines approaching a delivery of the volume mentioned.

Fig. 7 gives delivery, energy, and pressure of a small high-speed blower operating at constant speed, which in this case is 3400 r.p.m. This type of blower has a limited application in oil burning practice especially where it is desired to make an application of an individual blower to each furnace. It is an illustration of the strange characteristics in most fan-type blowers. Specifically, it shows that with well designed apparatus and at one pound pressure the blower delivers 100 to 125 cubic feet per minute with power requirements of about 1.75 kilowatts. This condition is for operation against a relatively small sized orifice, and, if the orifice is increased to allow a greater volume to pass, pressure will fall off rapidly and the energy required will increase

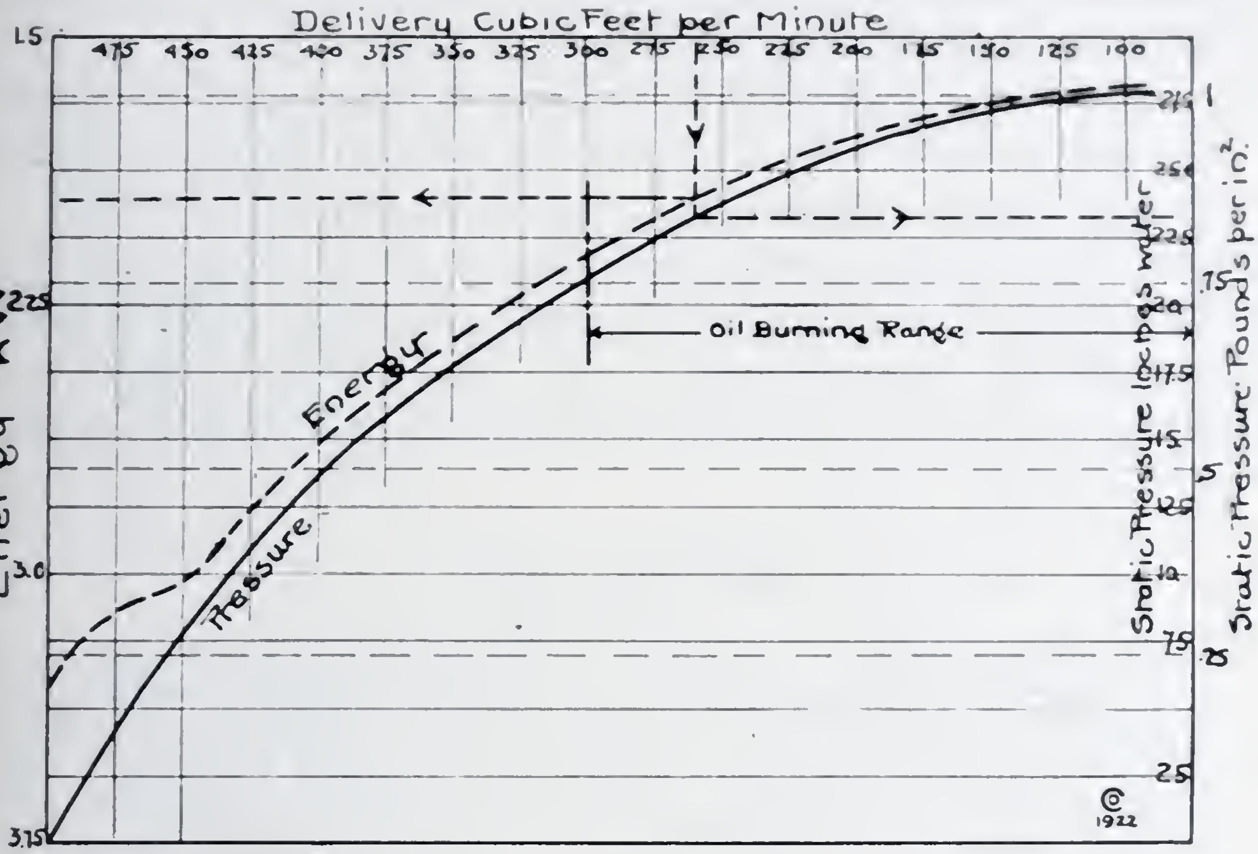


Fig. 7. Constant-Speed Performance of High-Speed Blower.

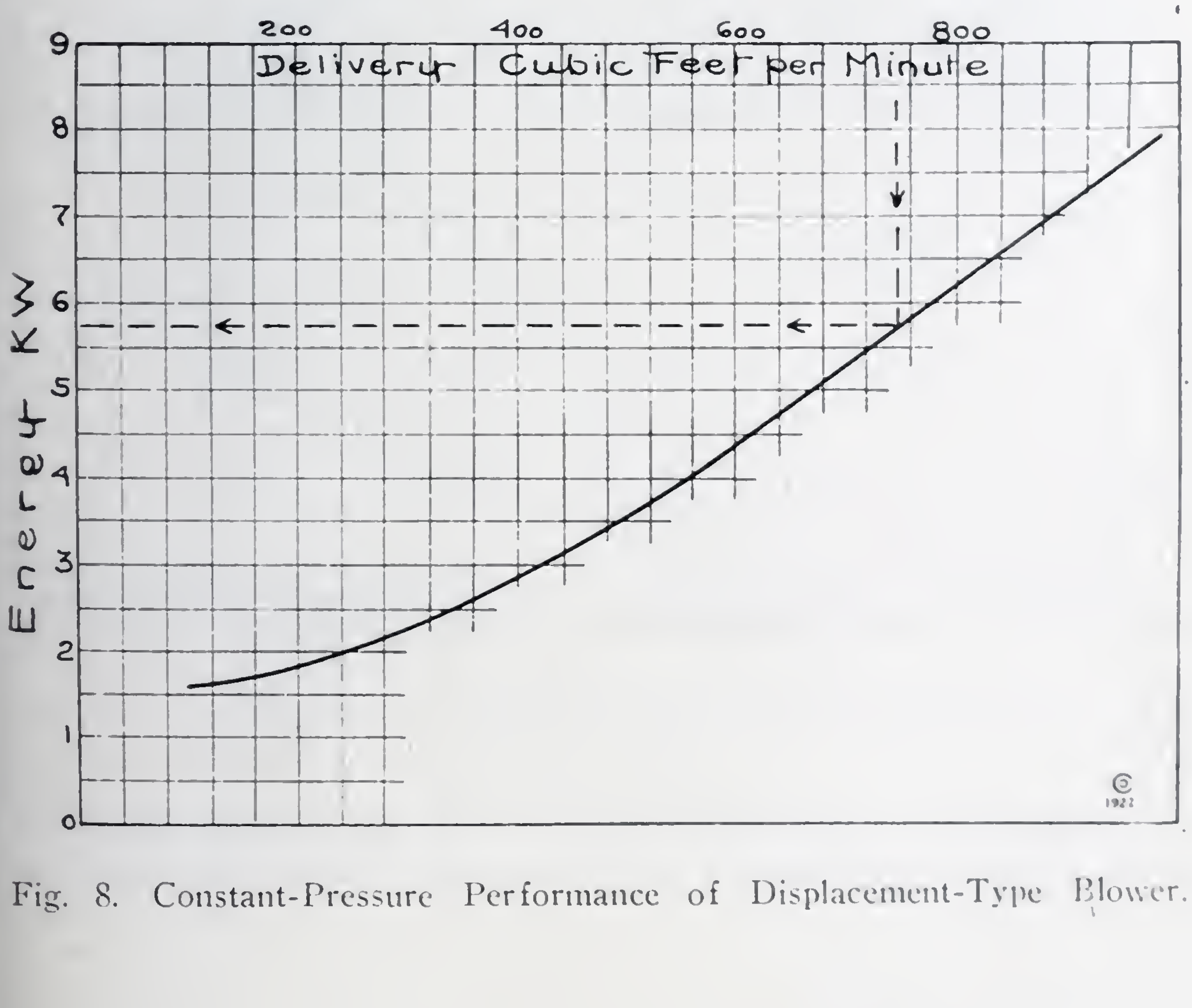


Fig. 8. Constant-Pressure Performance of Displacement-Type Blower.

somewhat in the same ratio as the pressure decreases due to the increasing weight of the air moved.

Fig. 8 is a composite curve of a displacement-type machine. In general, these machines operate at constant speed and against a constant area, maintaining a constant pressure. A change in the area of the nozzle without the use of an equalizing device will affect both pressure and energy greatly; therefore, these machines are generally equipped with a relief valve which prevents overloading and produces constant pressure by maintaining substantially constant volume.

The following, copied from the circular of a manufacturer of this type of machine, is self explanatory:

> "Blowers are of the positive type and openings cannot be closed or restricted before the blower is stopped without increasing the pressure and overloading the blower. This is entirely different from the fan type blower with which little increase in pressure is noted when discharge opening is closed. For protecting blowers against this overloading we suggest the use of relief valves."

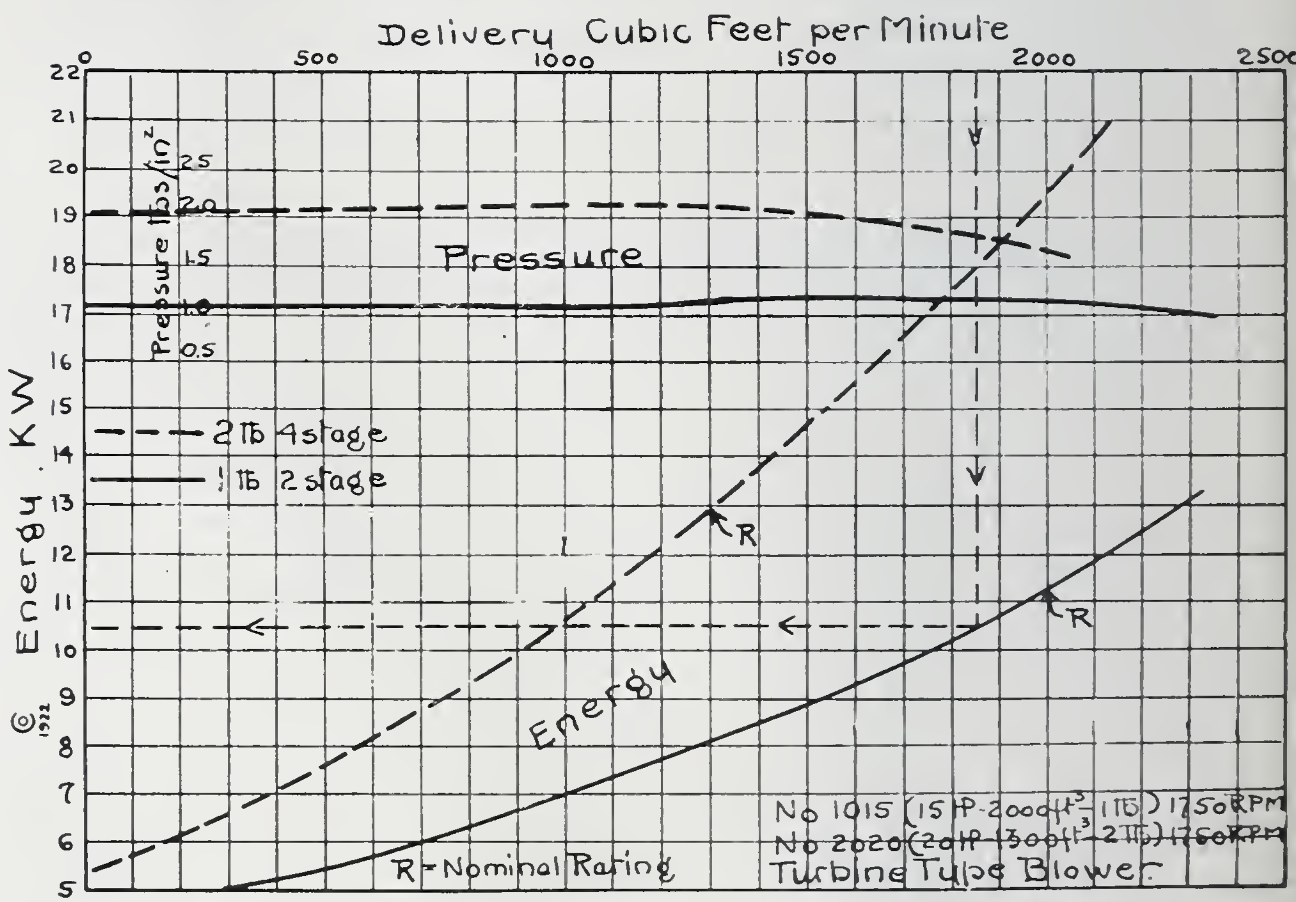


Fig. 9. Constant-Speed and Constant-Pressure Performance of Turbine-Type Blowers.

Fig. 9 gives operating characteristics, at constant speed, of a one-pound (two-stage) and a two-pound (four-stage) turbine-

type blower. With these machines, pressure is relatively constant while energy varies with volume which may be changed at will within the manufacturer's rating of extreme range, without fear of overloading the machines.

As clearly indicated, the turbine-type machine maintains speed and pressure constant, and any machine of a type employing four general characteristic factors that can maintain two of those factors as a constant has a great operating advantage over any other type of machine where if one factor is constant the other three must be variable.

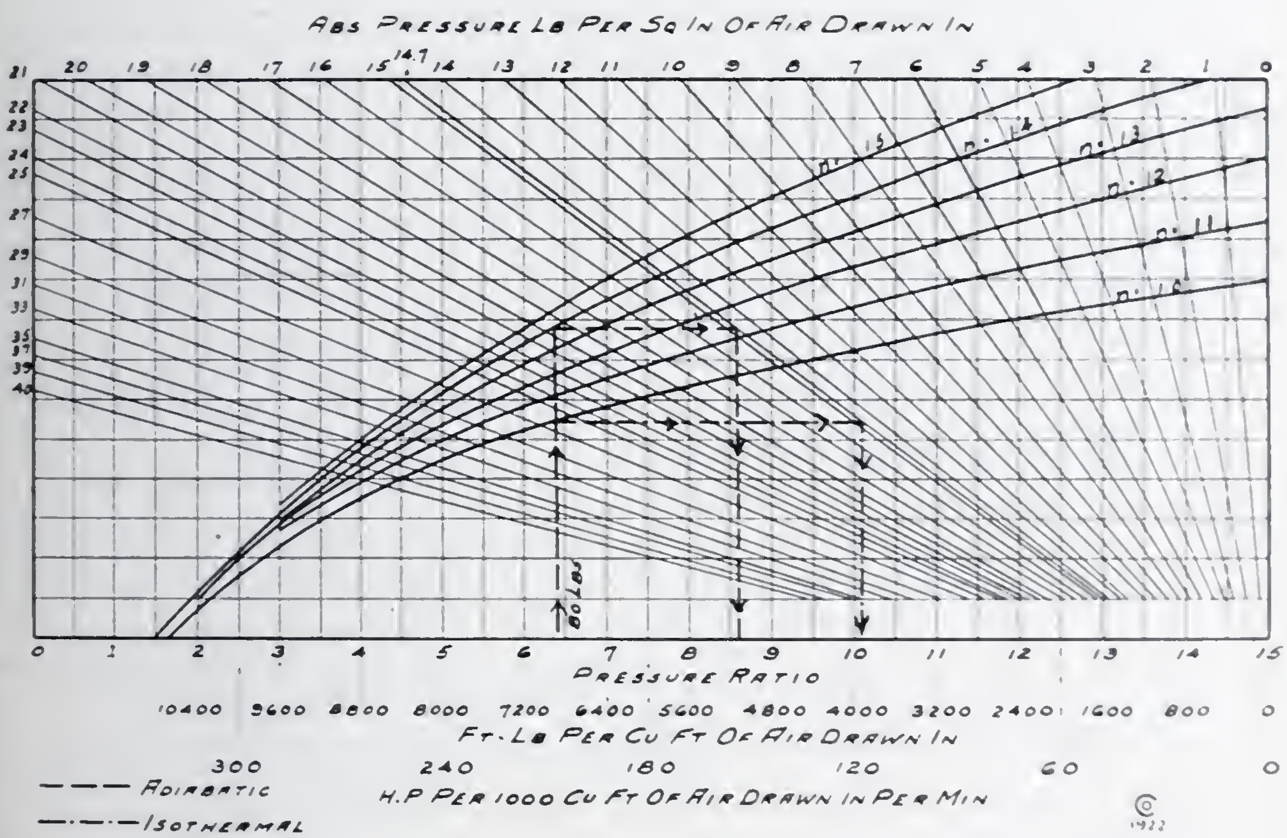


Fig. 10. Single-Stage Compressor Performance.

Fig. 10 gives the composite curve of Dr. Lucke* for single-stage compressor performance, and from this chart a considerable amount of information regarding compressor performance may be obtained. Figures are based on a delivery of 1000 cubic feet of free air per minute.

A sample reading is shown on a basis of 80 pounds gage pressure, and under isothermal operation the power to compress 1000 cubic feet of free air per minute is read to approximately

*Engineering Thermodynamics, by Charles E. Lucke. 1912. McGraw-Hill. New York. p. 169.

120 horse-power, while the power required for the same machines in adiabatic operation is approximately 150 horse-power. Isothermal operation is not found commercially and consequently the adiabatic figure should be used, the factor for the adiabatic change in air volume being 1.4. The power figures of this graph are those required for compression of air only and no account is taken of machine efficiency. For the single-stage machine the writer assumed this to be 78 per cent. and modified his figures accordingly.

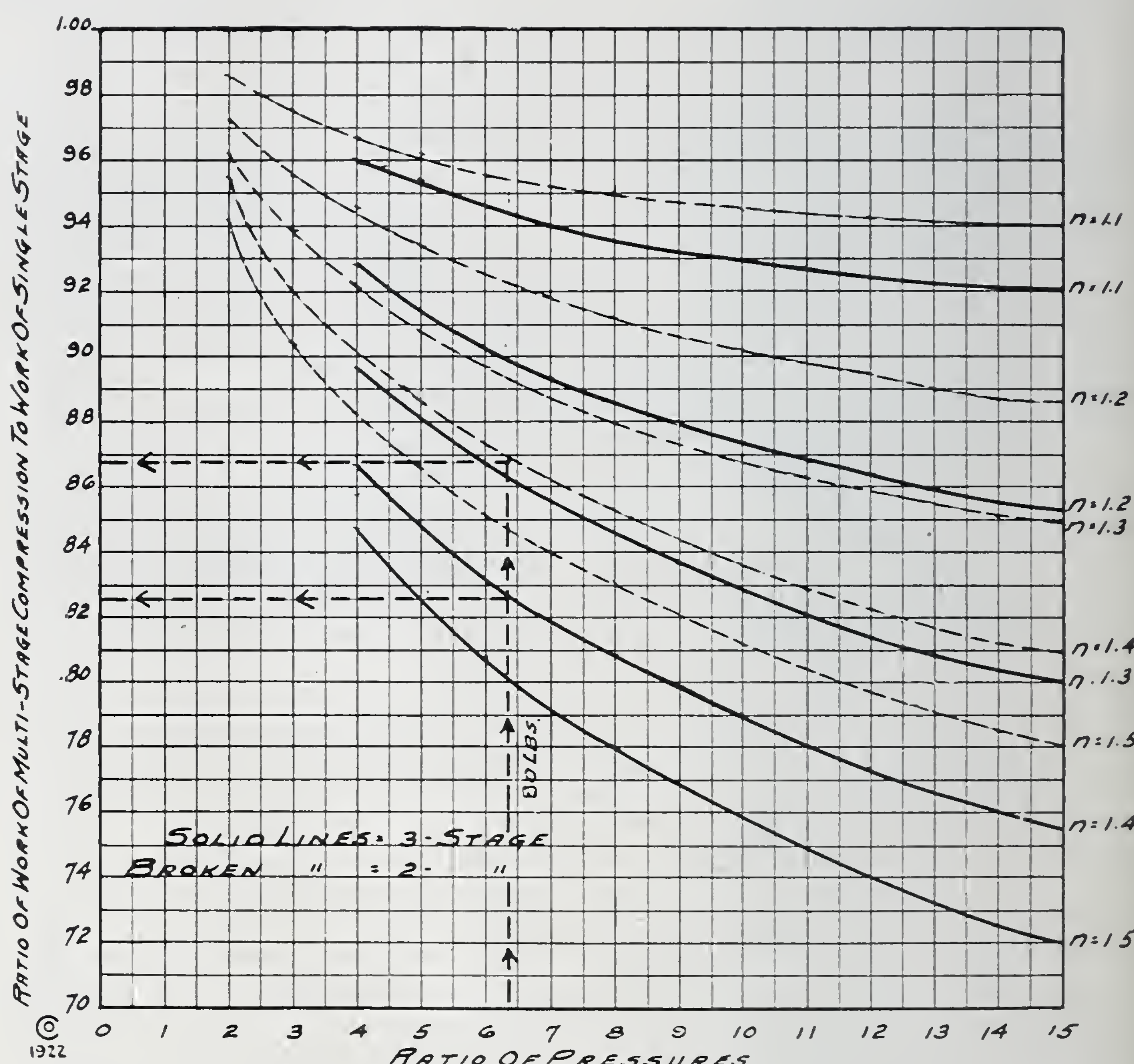


Fig. 11. Multistage Compressors Equipped with Intercoolers.

Fig. 11* gives the modifying factors for two-stage and three-stage compressors when equipped with intercoolers. The example

*Engineering Thermodynamics, by Charles E. Lucke. 1912. McGraw-Hill. New York. p. 179.

line is a continuation of the previous example carried out in Fig. 10, for 80 pounds gage pressure. As may be seen, a two-stage machine will take approximately 87 per cent. of the power required for the single-stage machine, while the three-stage machine will take approximately 82.5 per cent. of the power required for a single-stage machine.

COMPARATIVE COSTS OF AIR

Table II shows in comparative form the operating characteristics of all of the machines touched upon in this paper and also the calculated cost of compressing and moving air for oil burning purposes. In this table it is assumed that air is to be furnished in proper quantity for the complete combustion of 60 gallons of oil per hour and that 1500 cubic feet of free air are required for the combustion of a gallon of fuel or that a total of 1500 cubic feet of free air per minute must be supplied either by a blower or by the blower and the induction effect of the mechanical air.

Air quantity and the energy required to compress the air, as well as the cost of current required for the compression of air to burn 1000 gallons of oil, are indicated and an approximation of first cost of the machines, complete with motors, is given.

The cost of air per gallon with a compressor at 15 pounds is the lowest consistent with good atomizing and combustion conditions and it is shown that the cost of power for compressing it 80 pounds is over four times as great. The cost per gallon with one- and two-pound turbine machines is somewhat greater than with the 15-pound compressor; but, in spite of this, the turbine-type machine will likely be found the most economical in practice in the great majority of cases.

As has been previously stated, air supplied by machines under classifications 2 and 3 will atomize heavy oil where those in classification 1 will not. The cost of compressing at 0.12 of a cent per gallon for eight-ounce air would make a most excellent argument in favor of the mechanical system were it not for the fact that the selected oil required for good operation with this system would put a premium of at least 25 per cent. on the oil cost in a normal

fuel market, making the cost of the selected oil five cents per gallon when the heavy oils are available at four cents.

Operation of one- and two-pound turbine machines places a cost of 0.002 and 0.0025 of a cent, respectively, per gallon on the oil fuel, while the operation of a 15-pound piston machine adds a cost of 0.0015 of a cent per gallon, and the 80-pound piston machine, 0.006 of a cent per gallon.

AIR PIPING

The cost of piping the different types of blowing apparatus is specifically ignored due to the fact that every plant presents problems which are individual in every sense of the word and no general cost comparison can be reasonably drawn. It is a fact that it is generally more economical to have an individual blower for each furnace or at least to have a single blower serving a small group of furnaces. Large central-station blower equipment is not to be recommended, as piping costs are proportionally much larger and leakage and energy absorbed by friction losses in the pipes add additional costs which can well be eliminated.

CONCLUSION

Consideration of the subject matter and figures of this paper should clearly show that the proper method of burning oil is with air pressure under classification 2, or under some conditions with 15-pound air under classification 3.

All fuels are high priced whether they are coal, natural gas, manufactured gas or the liquid hydrocarbons, and in the years to come the tendency will probably be for fuel prices to continue an upward trend; therefore, to cut down fuel costs to the lowest possible figure, it is necessary that all of the economic factors entering into combustion reaction be given the most careful consideration and sound engineering principles applied to the installation, application, and operation of all fuel-burning equipment.

The conclusion drawn throughout the paper can be applied with only slight modifications to the combustion of pulverized

fuel. Naturally the requirements for atomizing as with oil are present only to a small degree but undoubtedly the practice is similar with both types of fuel.

No attempt has been made to cover oil burning equipment as used in the firing of steam boilers, open-hearth, glass, or other regenerative or recuperative furnaces. Conditions of combustion set up with the latter type of equipment vary so radically from those found in industrial furnace application that results given in this paper can in no way be applied.

DISCUSSION

Mr. J. C. Hobbs:* Mr. Buell is to be commended for this paper. His presentation of the subject appears to be quite complete, and if I add anything to the value of the paper my remarks will be general, applying to combustion problems in general.

It is very encouraging to note the change of attitude which has taken place during recent years in regard to the control of air. Only a few years ago it seemed to be the general impression that coal, oil, gas, etc. were the "fuels", and that air could be obtained for nothing, and was therefore quite "cheap". To-day a few engineers at least seem to realize that the process of combustion consists of the chemical combination of two or more elements, with the resultant generation of heat; and some of these engineers have come to the conclusion that one of these elements is just as important as the other, and that oxygen deserves to be classed as fuel just as much as the other element. As a matter of actual fact, an increase in the amount of air used in the furnace, increases the fuel cost even though air is obtained free.

After all, the process of combustion is a scientific one which is comparatively simple, and which can be solved successfully when definite control is exercised over the supply of each of the elements being fed to the furnace. Some method of measuring the amount of oil, gas, or coal fed to the furnaces is accepted by all as being desirable. It is equally desirable to be able to measure the quantity of air, oxygen, or other combustion-supporting ingredient; and it is doubly worth while to have means available by which to control the rate of feeding both the elements, so as to obtain that predetermined mixture, which will result in the highest efficiency and the lowest unit costs for the benefits obtained. In other words, instead of the hit-or-miss systems which have been employed heretofore in practically all combustion methods, a definite and positive means of controlling the process should be worked out and used.

*Manager, Allegheny County Steam Heating Co., Pittsburgh.

The principal factors in the process of combustion consist of feeding the elements to the furnace in the proper proportions; mixing the elements thoroughly; and maintaining a temperature condition sufficiently high to cause the chemical combination to be effected within a practically limited period of time. Both the time and the furnace volume required are dependent upon the primary factors of intimacy of the mixture and the temperature. If a very thorough mixture could be supplied to the furnace, the amount of volume required could be greatly reduced because a shorter flame would result.

Furnace volume and amount of excess air admitted also have a rather definite relation. If no excess air is used the volume must be large and the movement of the gas in the furnace such that each particle of the combustion ingredient must be brought into contact with its respective particle of combustion-supporting ingredient in order to prevent losses due to incomplete combustion. As a practical proposition some excess air is admitted to the furnace, so that none of the combustible ingredient, which must be purchased, is allowed to escape without generating heat. As previously inferred, the thoroughness of the mixture also has a definite relation to the amount of excess air required in order to insure complete combustion.

Mr. C. W. Heppenstall:* Have you figures to show the saving on the use of preheating air in oil-fired furnaces?

Mr. W. C. Buell, Jr.: I have collected a great many figures on the amount of heat returned to the furnace in the air when heated to different temperatures.

Mr. C. W. Heppenstall: Can you give me, in round figures, the saving that could be effected by using preheated air; that is to say, on a given furnace, how much oil could be saved over the atmospheric temperature with air preheated to 300 degrees F., then to 600 degrees F., and then to 800 degrees F.?

*Treasurer and General Manager, Heppenstall Forge & Knife Co., Pittsburgh.

Mr. W. C. Buell, Jr.: Assuming that the fuel is being burned perfectly, I would expect that preheating the air to 300 degrees would return five per cent. of the total fuel used, as sensible heat. At 600 degrees this would amount to approximately 12 per cent., and at 900 degrees it would amount to approximately 18 per cent. It is, of course, assumed in the above figures that all of the air required for combustion is preheated to the figures mentioned.

Mr. F. K. Howell:* I would like to ask if the speaker can give us the approximate cost of operating with steam atomization where you have plenty of steam and no cost for water, as compared with air atomization.

Mr. W. C. Buell, Jr.: Figures are rather indefinite, and vary greatly. I have figures which indicate that where tar is used as a fuel approximately one pound of steam is used per pound of tar. In the case of the regenerative furnace, quantities of steam required are much smaller—probably not over 0.2 or 0.3 pound of steam per pound of fuel.

Mr. B. B. Weinberg:† At what pressure do you deliver the oil to the steel-heating furnaces?

Mr. W. C. Buell, Jr.: It depends on the oil and the system. Preheating air will greatly improve results over cold-air practice, and the tonnage of steel per unit of fuel will be increased from greater temperature differentials. I have used air preheated as high as 1600 degrees F., in forging practice, and the economies from this amount of preheat have been almost unbelievable. In your practice, Mr. Heppenstall, do you not have to operate at 75-pound oil pressure to secure sufficient burner capacity at the higher burner ratings?

Mr. C. W. Heppenstall: Comparatively speaking, our ex-

*Superintendent, Compressing Stations, Philadelphia Co., Pittsburgh.
†Production Manager, Heppenstall Forge & Knife Co., Pittsburgh.

perience with the use of oil pressure has been quite different from yours. Whether you are right or whether we are right, I am not prepared to say. You understand, of course, that we are not in the business of selling oil equipment. We do burn oil, and we find that we get the best results when we use an oil pressure of 75 to 80 pounds.

Mr. W. C. Buell, Jr.: Are you using a mechanical system?

Mr. C. W. Heppenstall: Yes.

Mr. W. C. Buell, Jr.: That is different.

Mr. C. W. Heppenstall: What do you mean by mechanical?

Mr. W. C. Buell, Jr.: You are forcing oil through small orifices, depending on this action to atomize it?

Mr. C. W. Heppenstall: Yes.

Mr. W. C. Buell, Jr.: You are using expensive oil?

Mr. C. W. Heppenstall: No sir; 26 to 32 gravity.

Mr. W. C. Buell, Jr.: It is light and fluid?

Mr. C. W. Heppenstall: It is when you heat it?

Mr. W. C. Buell, Jr.: Then you do heat it?

Mr. C. W. Heppenstall: Yes, we heat it.

Mr. W. C. Buell, Jr.: You are using what I call a mechanical system, and in that the pressure runs higher than it does in what I have, throughout the paper, called air atomizing.

Mr. C. W. Heppenstall: It might be interesting for you to know how we use oil in our heating furnaces. We use a

General Electric Company 16-ounce pressure turbo-blower for supplying air to our furnaces. This air is passed through pipes in a preheating chamber which is heated by reflected heat, giving the same effect as a regenerative furnace. When this air comes out of the regenerative chamber, and is delivered to the furnace, it is heated to approximately 700 degrees F. We pump the oil under 80 pounds pressure, and heat it to 180 degrees F. Our furnaces, when running full, have a transparent heat, and we have no smoke, and no stacks on our furnaces. The heating furnace that I am talking about is our standard heating furnace, in which we heat ingots from 12 to 40 inches in diameter. This furnace has a hearth 9 feet wide and 16 feet deep. The height of the furnace varies with the different classes of work which we handle. In our largest furnace, which is approximately six feet high, we can heat a ton of steel on less than 25 gallons of oil.

Mr. W. C. Buell, Jr.: As a matter of information it might be interesting to state that in marine practice with a mechanical atomizing system we use oil frequently under pressures up to 300 pound gage.

CONTINUOUS-TRAFFIC LIFT BRIDGES PROPOSED FOR ALLEGHENY RIVER AT PITTSBURGH

By A. A. Henderson*

BRIDGING NAVIGABLE STREAMS

Rock Island Bridge Case. In May, 1856, the steamboat *Effie Alton* struck one of the piers of the Rock Island bridge over the Mississippi River, and was wrecked and burned. One pier of the bridge was also destroyed. The boat owners sued the bridge company, alleging:

1. That the river was the great highway for the commerce of the valley, and could not legally be obstructed by a bridge.
2. That this particular bridge was so located with reference to the channel of the river at that point as to make it a peril to all water craft navigating the river and an unnecessary obstruction to navigation.

The first proposition had not at that time been directly passed upon by the Supreme Court of the United States, and the case was felt to involve the future course of western commerce.

Right to Bridge Established by Lincoln's Arguments. We should find the arguments for the defense of peculiar interest at this time because of the points involved, and especially so because the main arguments were presented by Abraham Lincoln, whose clear statements and logical conclusions resulted in the court fully sustaining the right to bridge so long as it did not unnecessarily obstruct navigation.

He contended that *one man had as good a right to cross a river as another had to sail up or down it;* that these were equal and mutual rights which must be exercised so as not to interfere with each other, like the right to cross a street or highway and the right to pass along it.

*Assistant County Engineer, Allegheny Co., Pittsburgh.

From this undeniable right to cross the river he then proceeded to discuss the means for crossing. Must it always be by canoe or ferryboat? Must the products of all the boundless fertile country lying west of the river for all time be compelled to stop on its western bank, be unloaded from the cars and loaded upon a boat, and after the transit across the river be reloaded into cars on the other side, to continue the journey east? A bridge with piers, he declared, was a necessity in railroad engineering for getting across the Mississippi River. There was, he said, no practicability in the project of building a tunnel under the river, for there "is not a tunnel that is a successful project in this world". A suspension bridge cannot be built so high but that the chimneys of the boats will grow up till they cannot pass. The steamboat men will take pains to make them grow. The cars of a railroad cannot without immense expense rise high enough to get even with a suspension bridge or go low enough to get through a tunnel; such expense is unreasonable.*

As a result of the court decision in this notable case, land traffic has been conceded the right of crossing rivers by means of bridges, usually constructed with piers.

The ingenuity and resourcefulness of American engineers have developed a variety of construction seeking to attain economical bridges with the minimum of inconvenience to land traffic and avoiding unreasonable obstruction to water traffic.

RAISING OF LOCAL BRIDGES

It is assumed that practically all of those interested in this discussion are also familiar with events resulting in the present decree of the War Department regarding certain Pittsburgh bridges, and a brief recital of outstanding features will be sufficient.

Raising the Pittsburgh bridges which span the Allegheny River has been agitated since 1903. Numerous hearings and investigations have been conducted by the United States War De-

*From Life of Abraham Lincoln by Ida M. Tarbell. Doubleday, New York. 1900; and Life and Works of Abraham Lincoln, Centenary Edition. Edited by Marion Mills Miller. Current Literature Pub. Co., New York. 1907.

partment. These have terminated in the decree of the Secretary of War—issued March 23, 1917; suspended, March 1918; and revived March 10, 1919—which declares that the present bridges are obstructions and must be altered by changing spans and increasing heights above water.

It is thus ordered that the following schedule be observed in the alteration of the bridges:

Bridge	Work commenced before	Work completed before
Sixth Street	April 2, 1921	April 2, 1923
Seventh Street	April 2, 1920	April 2, 1922
Ninth Street	April 2, 1920	April 2, 1922
Thirtieth Street	April 2, 1922	April 2, 1924
Forty-third Street	April 2, 1919	April 2, 1921

The Sixteenth Street obstruction to navigation was removed when the bridge was burned, April 23, 1918 and a new bridge, satisfactory to the War Department, is now under construction at Sixteenth Street.

The Thirtieth Street bridge was partly destroyed by fire July 8, 1921. Plans for reconstruction contemplate the elimination of railway grade crossings. This will place the proposed structure at the elevation required by the War Department, and the resulting type of construction will involve nothing unusual.

Plans have been completed for a new bridge at Fortieth Street. This will cross railway tracks above grade and be at an elevation satisfactory to the War Department. This proposed bridge will replace the Forty-third Street bridge, and the latter will then be abandoned and removed.

The problem now remains to determine what type of construction (subject to approval of the War Department) will best serve the various interests concerned in the reconstruction of the Sixth Street, Seventh Street, and Ninth Street bridges.

Lincoln's grasp of the subject is shown by his discussion of the four available methods of effecting a stream crossing.

1. Tunnel.
2. Boat.
3. Low bridge (with draw and piers).
4. High bridge (spanning river clear of boats).

His arguments established before the court that the third type—low bridge with draw and piers—afforded a just recognition of the equal and mutual rights to cross a stream and to sail up and down it. It is a matter of interest that this type of construction has received a minimum amount of consideration in dealing with our local problem.

MOVABLE BRIDGES

Prevalency. Any kind of a movable bridge is a novelty to a majority of our citizens, and because we do not see one daily we might conclude that this type of bridge is unusual. Such is not the case, however, for records indicate that a complete list of bridges over navigable streams would include many movable structures. Not having such a list, this conclusion is based upon the results of a search of the acts of Congress. These are used as the best available source of information, since a special act is necessary to permit the erection of each separate bridge.

The 56th and 57th Congresses* passed 108 acts authorizing a like number of bridges, designated as follows:

Type	Number	Per cent.	
High (Clear of water craft)	8	7 per cent.	
Draw (movable structures)	33	31 per cent.	
High or draw (optional with builder)	26	24 per cent.	Doubtless include both types
Type not specified	41	38 per cent.	

Tennessee River Bridge Acts. The Tennessee River was investigated as a specific case. This stream is three times the length of the Allegheny and drains more than twice the territory. Within the last 35 years, 45 acts have been passed authorizing bridges over this stream, as follows:

Type	Number	Per cent.
Draw	19	42 per cent.
High or draw (optional with builder)	9	20 per cent.
Type not specified	17	38 per cent.

Prominent in the above list is the Illinois Central Railroad

*The acts of the 56th and 57th Congresses are chosen for reference because they represent the latest date to which the acts referring to bridges over navigable streams have been compiled.

bridge at Gilbertsville, Kentucky. This is a drawbridge, not far above the mouth of the stream.

It is admitted that not all bridges authorized by Congress are built. A list of existing structures would probably show some variation from the figures just given. The information is sufficient, however, to justify the statement that there is a widespread demand for bridges of the movable type, and that Congress has recognized this demand and is permitting the erection of such bridges over many important rivers.

Movable Bridge a Compromise. It is physically possible to build each bridge high enough to allow all water traffic to pass beneath, but in many cases this would make the cost prohibitive and would erect a financial barrier to the proper expansion of land traffic. Going to the other extreme, a very material reduction in cost would result from building bridges without regard to accommodating water craft. This would erect a physical barrier to the movement of boats.

To secure the combined welfare of both land and water traffic, mutual concessions are necessary and a movable bridge frequently becomes the only solution. Every movable bridge is thus a compromise. Economy compels the adoption of this type of structure, and even though all such bridges now in use obstruct both land and water traffic, the advantages they otherwise afford make their use desirable. Having in mind the practice of constructing movable bridges over similar streams for the sake of economy, we are justified in investigating the possibilities of this type of construction for the Allegheny River. If the advantages of convenience and economy outweigh the disadvantages of traffic interruption so greatly as to make existing types of movable bridges worthy of consideration, it follows that a modified construction, free from the annoyance of traffic interruption and still affording all the advantages enjoyed by movable bridges, is worthy of serious consideration. The results just indicated may be obtained by means of the continuous-traffic lift bridge.

LIMITATIONS IN CONSTRUCTING NEW BRIDGES

Clearance and Grades. A study of the testimony, findings and decree resulting from the various hearings upon the Allegheny River bridges reveals the following limitations established for the reconstruction of these bridges:

1. The United States Engineers, after hearing testimony and measuring the heights of river boats, determined that 33 feet is the clearance necessary for water craft upon the Allegheny River; and that the bridges should be built at an elevation high enough to provide this clearance until the water reaches the 20-foot stage, at which stage the locks are no longer in use.

2. Engineers for the city and county were united in the opinion that the maximum allowable grade upon the bridges should not exceed three per cent.

Each of the foregoing conclusions proceeds from engineers who, by training and experience, must be considered well qualified to pass judgment within their respective fields.

Limitations Satisfactorily Observed by Continuous Lift. To reconstruct the bridges in accordance with the limitations just mentioned would involve an extensive revision of our street grades and result in property damages estimated at from six to ten millions of dollars.

The continuous-traffic lift bridge has been proposed as a satisfactory solution. It may be built with spans of the lengths required by the War Department; it permits unobstructed passage for water craft at all navigable stages; it does not interrupt traffic over the bridge; it provides an average roadway grade materially less than the specified maximum of three per cent.; and it accomplishes these results without any material alteration in street grades or damages to abutting properties.

THE CONTINUOUS-TRAFFIC LIFT BRIDGE

Local Application. The superstructure of the proposed bridge would be placed 33 feet above the ordinary stage of water, known as pool-full stage. This is substantially the height of the three present bridges.

At each of the two piers would be installed some mechanism (hydraulic lift contemplated) capable of raising and lowering the portion of the bridge supported by each pier. The superstructure could then be raised and lowered as the water in the stream rises and falls, keeping the structure 33 feet above the surface of the water at all times.

Raising the entire channel span and tilting the adjoining spans at the same time, permit traffic to pass over the bridge at all times, whatever position the bridge may occupy. The 33-foot clearance is maintained in the channel span only.

The masonry and superstructure of the proposed bridge will be substantially the same as that required for a fixed bridge of the same length and spans. The only additional expense for the former is the cost of installing the necessary mechanism for operation. The hydraulic lift, though possibly not the cheapest mechanism, will apparently be the most effective and satisfactory, but other means may be employed if desired. If there be no occasion to operate at a speed greater than the rate at which the river rises and falls, the cost of installation and operation will be materially less than if it should be necessary to provide for frequent and rapid operation.

Bridge Attendants. The necessity of employing operators for a movable bridge should not be considered as introducing a new feature in the maintenance of local bridges. The present bridges are under the constant supervision of persons employed for that special purpose and this practice will doubtless be continued with respect to the new bridges, regardless of the type erected. By judicious selection and a proper assignment of duties, the attendants required for the movable bridges need not differ greatly in number from the force that otherwise would be employed.

The proximity of the three bridges to each other affords an opportunity to simplify operation and reduce costs. In considering the cost of maintenance it is essential to remember that operations will probably be infrequent and limited in extent, and that not the least important duty will be to prevent deterioration of equipment during long periods the bridge may remain at rest.

Operation of Bridge in Relation to Length of Roadway. The roadway of the bridge will lengthen when the bridge is elevated. Apparently the most satisfactory movement of the tilting span will result from the point of support at the pier end of the span moving in a vertical plane, and the other point of support at the shore end moving in a horizontal plane. This will result in the separation of the floor (caused by the raising of the bridge) being about equally distributed between the two ends of the tilting span. The maximum amount of separation will average about three inches for a bridge of the dimensions under consideration. It will be seen that the separation of roadway, caused by raising the bridge, introduces no feature which is not already encountered at the expansion joints of all large bridges.

Adoption Subject to Approval by War Department. The question properly arises as to whether the continuous-traffic lift bridge has any features which would justify the War Department in withholding approval. Prevailing practice indicates that the Department must be assured that such a bridge would not become an "unreasonable obstruction" to navigation and that its erection would result in substantial advantages to traffic.

The advantages arising from economical construction have already been discussed at sufficient length.

Obstruction to Navigation. In determining whether a bridge offers "unreasonable obstruction" to navigation, the two main features to be investigated are:

1. The horizontal, or lateral, encroachment and resultant obstruction caused by location of piers within that portion of a stream which is navigable, either continuously or during certain stages of water.

2. The overhead, or vertical, encroachment and result-

ant obstruction caused by the superstructure extending below the height necessary for the free passage of water craft.

Bridge piers placed within navigable water constitute such a well known menace to navigation that the location of each one is carefully studied by the federal authorities and each pier is subject to strict requirements as to rip-rap, pier protection, navigation lights, etc.

If a single span extending across the full width of stream were equally as convenient for land traffic, and no more expensive, it is beyond dispute that no bridge piers would be permitted within limits ever used by water craft. It follows without argument that wherever bridge piers are permitted within such limits, it is an acknowledgment of the rights of land traffic to convenience and economy in erecting bridges, even though it results in a measure of obstruction to navigation. By the same reasoning the consent to overhead obstruction, arising from movable bridges, may be said to be a similar acknowledgment of the rights of land traffic.

The War Department, in making its present decree, has taken the position that the community's right to build bridges with greater convenience and economy is of such importance that water craft on the Allegheny River must submit to the undeniable restriction and obstruction which will arise from the existence of two piers reducing the natural channel at each bridge site.

When it becomes apparent, through a fully developed design if need be, that the proposed new type of bridge affords a convenience and economy greater perhaps than that already obtained from the permission to construct piers; that it conforms to the span lengths and clearances required, and introduces no material obstruction in addition to that already conceded through the erection of piers; and that it admits of a design which assures operation no less reliable than that required in other movable bridges, it would not be considered inconsistent with previous action if the War Department should grant the slight concession of permitting the bridge to be built in such a manner that the superstructures might be lowered whenever a low stage of water

may make it unnecessary for the bridge to remain at its high elevation.

Importance of Expert Design. Before submitting the matter to the War Department for approval, it is essential that detailed plans be prepared by some person of such wide experience that the War Department will not hesitate to recognize the resultant design as dependable and authoritative.

Fig. 1 shows fluctuation of the Allegheny River at Pittsburgh for a continuous period of 20 years. It furnishes definite data

Fig. 1. Fluctuation of Water Stage in Pittsburgh Harbor.

on the subject of floods—their height, frequency and infrequency at different periods of the year, and similar information.

It is noteworthy that each year has a period of low water and negligible fluctuation extending through several months, frequently more than half of the year. The continuous-traffic lift bridge is adapted to take full advantage of this condition.

Fig. 2 confirms the general impression that the greatest number of floods occur during the first three months of the year. It also shows that outside of these first three months, the stage has

exceeded 20 feet only 10 times in 20 years, which indicates that during the period from March to January the probability that the water will never reach the 20-foot stage is as great as the probability that it will exceed that stage. It shows that during the 20-year period the Allegheny has never reached the 20-foot stage from May till November.

The lower part of the sketch shows the comparatively few days of water in the higher stages and the many months of low water.

The following prediction of annual floods is offered with a full realization that any such schedule produced will show wide

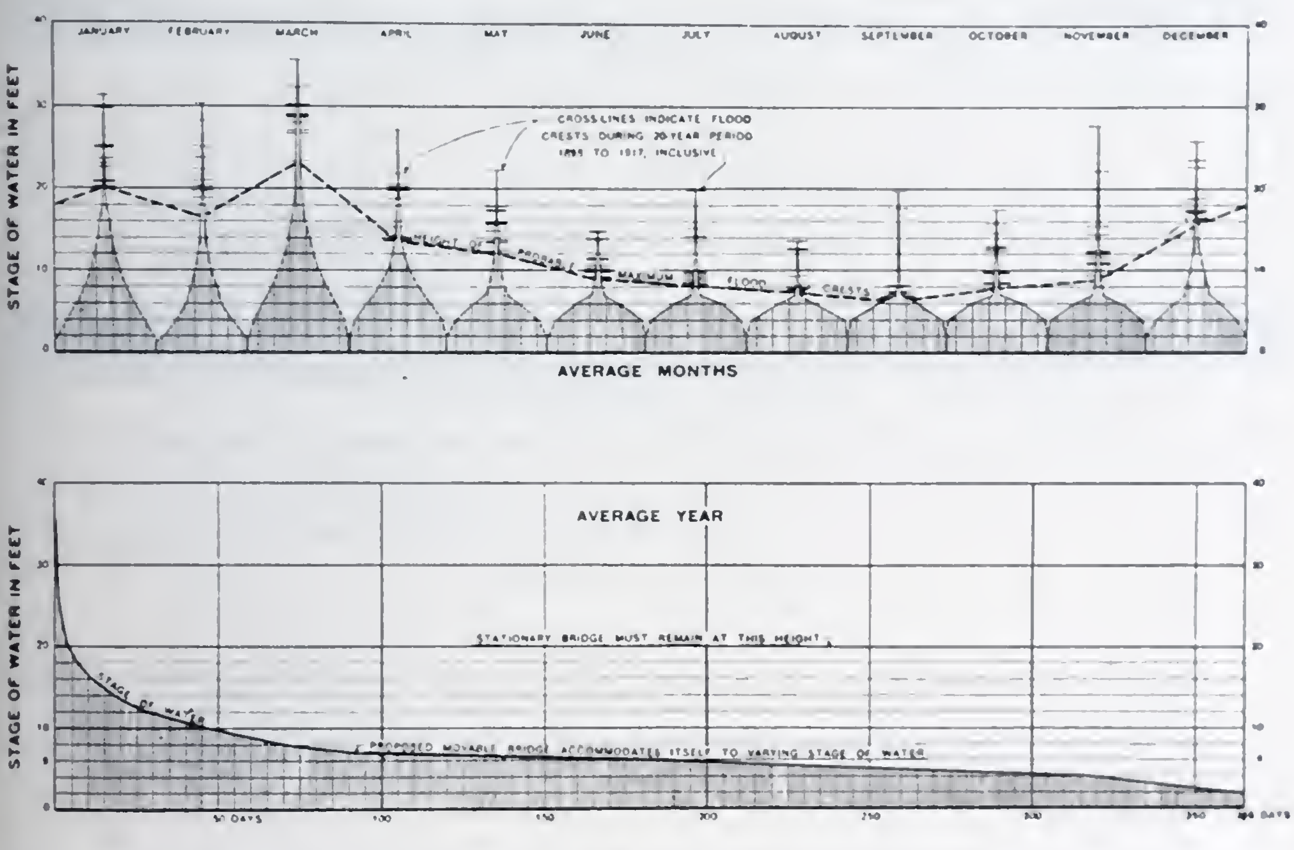


Fig. 2. Average Duration of Water Stages in Pittsburgh Harbor.

variations when compared with exceptional years; nevertheless, it shows the conditions which will prevail through a continuous period of years:

The 20-year record indicates the probability of six floods annually which will exceed the 14-foot stage. The probable heights of these floods are, respectively, 28.0, 22.0, 19.5, 17.0, 15.5, and 14.5 feet.

Fig. 3 is constructed solely for the purpose of illustrating the controlling features of the continuous-traffic lift bridge.

Since the vertical scale is greatly exaggerated in comparison with the horizontal, no attempt is made to suggest finished outline of structure or details of design.

The sketch shows results which may be obtained at the site of the Sixth Street bridge, without disturbing streets.

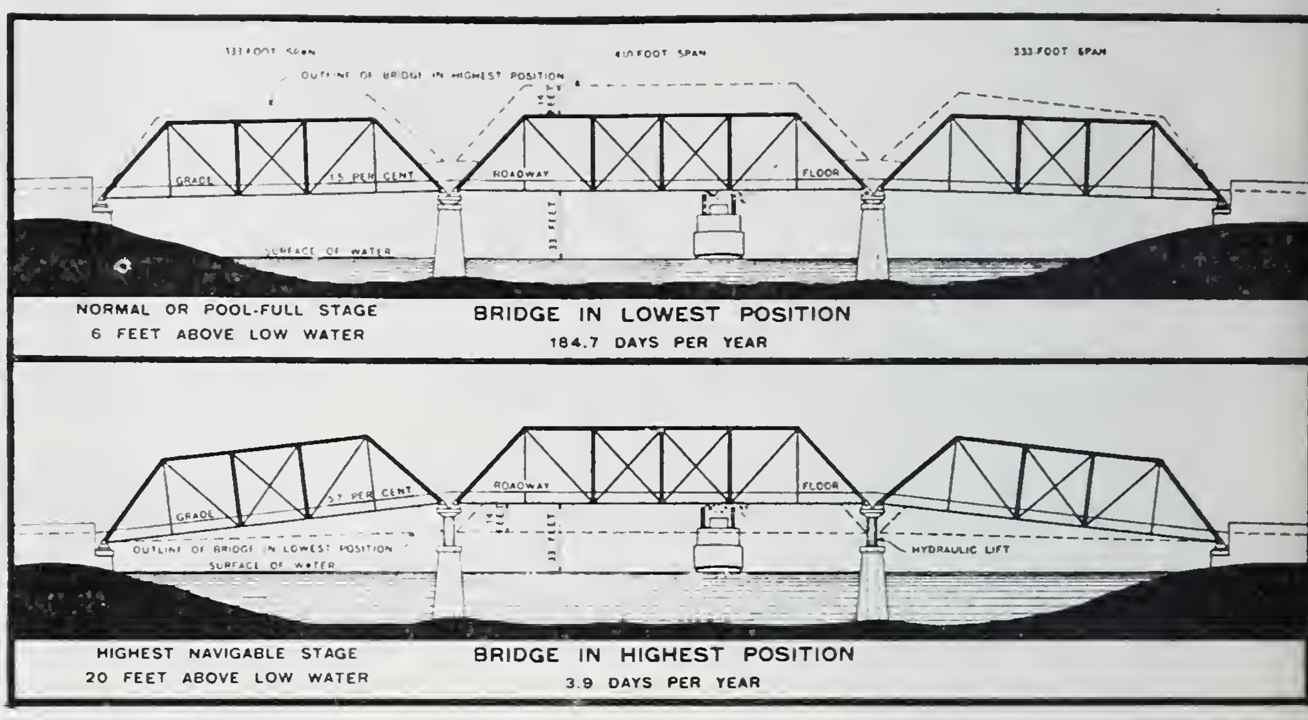


Fig. 3. Proposed New Type of Movable Bridge to Span Allegheny River at Pittsburgh.

Table I shows the average duration of various water stages in the Allegheny River, and the consequent variation in grade on the proposed bridge.

TABLE I. WATER STAGES AND RESULTANT GRADE ON BRIDGES

Water stage in feet	Average duration in days per year	Per cent. grade on shore spans
6 or less	184.7	1.5
6 to 8	108.9	1.8
8 to 10	24.7	2.4
10 to 12	17.9	3.0
12 to 14	9.7	3.6
14 to 16	7.0	4.2
16 to 18	4.4	4.8
18 to 20	2.9	5.4
20 or more	3.9	5.7

Fig. 4 shows proposed piers and abutments for each of the three bridges, located as required by decree of the War Department. It also gives a connected plan of streets on either side of the river.

Fig. 5 (folding plate) shows, by profile, results which may be obtained by constructing fixed bridges at the elevations required by decree of the War Department; and not exceeding three per cent. grade on the roadways of the bridges. This will elevate the grade of Duquesne Way, ranging from 6.85 feet at Sixth Street to 11.17 feet at Seventh Street; and make necessary the elevating of Pennsylvania Railroad tracks ranging from 6.96 feet at Seventh Street to 7.62 feet at Ninth Street.

Fig. 6 (folding plate) shows results, by profile, which may be obtained by use of the continuous-traffic lift bridge at each of the three sites. Six per cent. is the maximum grade adopted for the tilting spans in the highest position. This would create no change in street grade on Duquesne Way at Sixth Street, and but slight changes at Seventh and Ninth Streets. This plan makes it unnecessary to raise the overhead Pennsylvania Railroad tracks. The Baltimore & Ohio Railroad tracks control grades at the northerly end of each bridge.

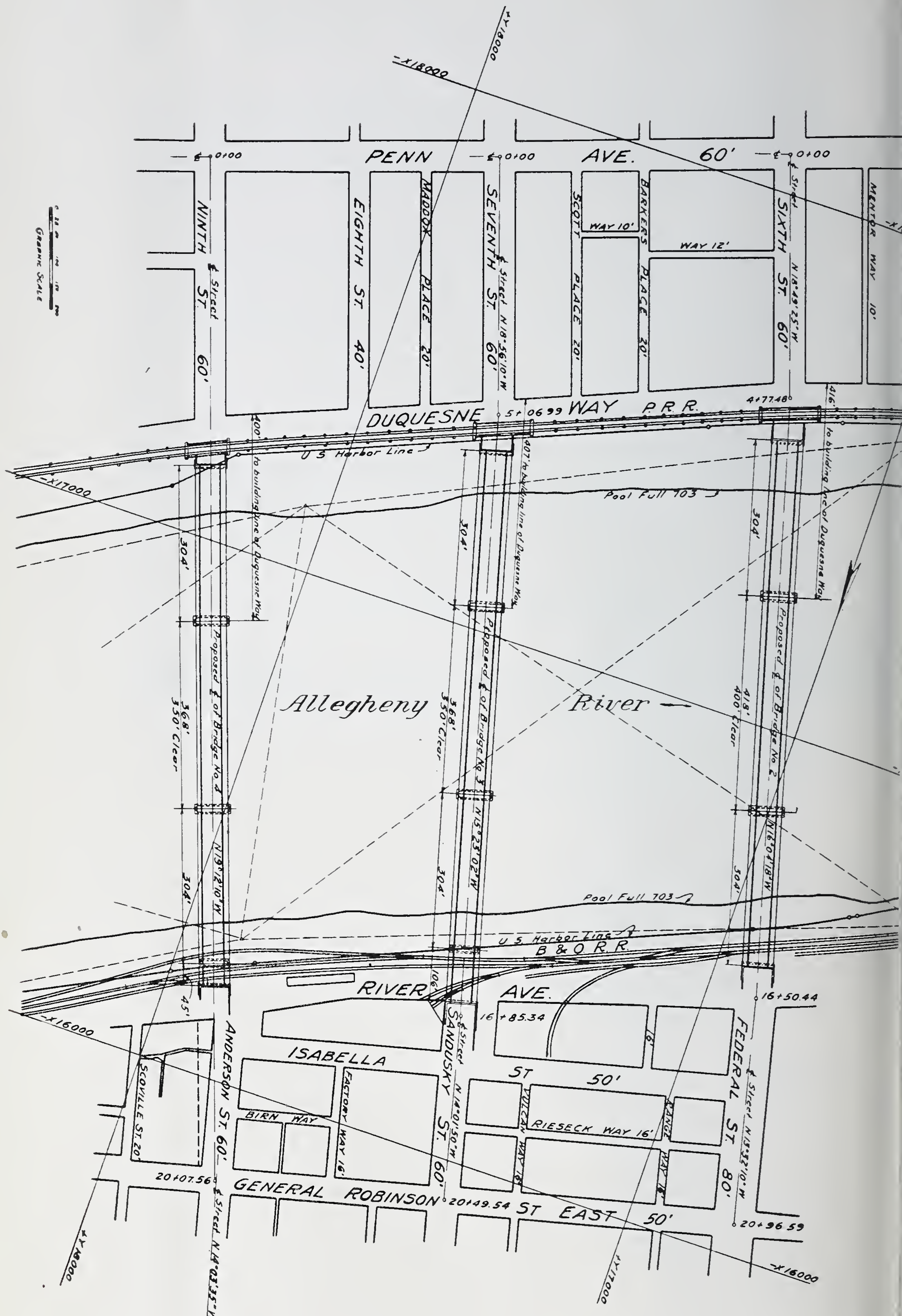


Fig. 4. Proposed Piers and Abutments Located in Compliance with Order of War Department.

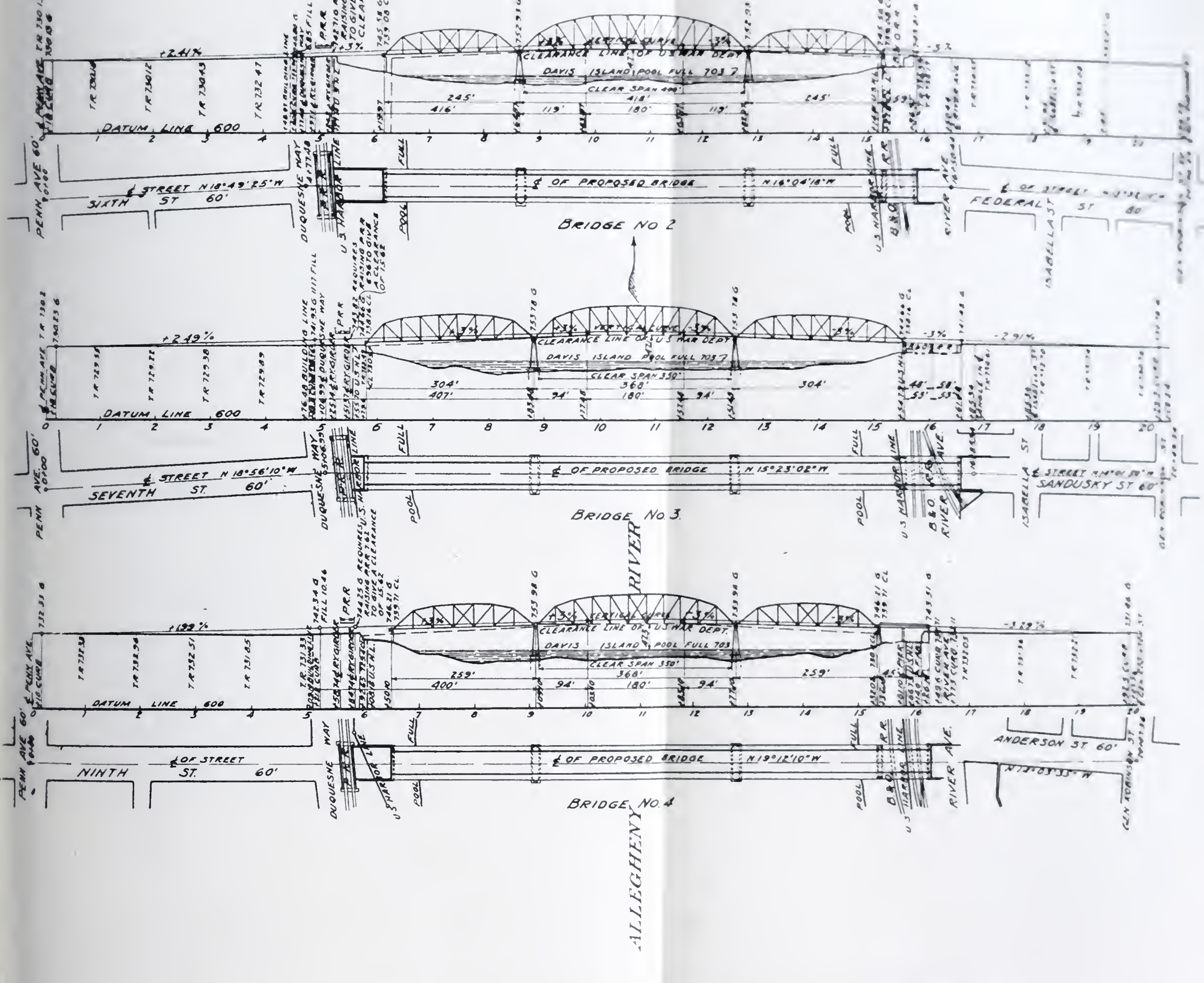


Fig. 5. Profiles Illustrating Construction of Fixed Bridges.

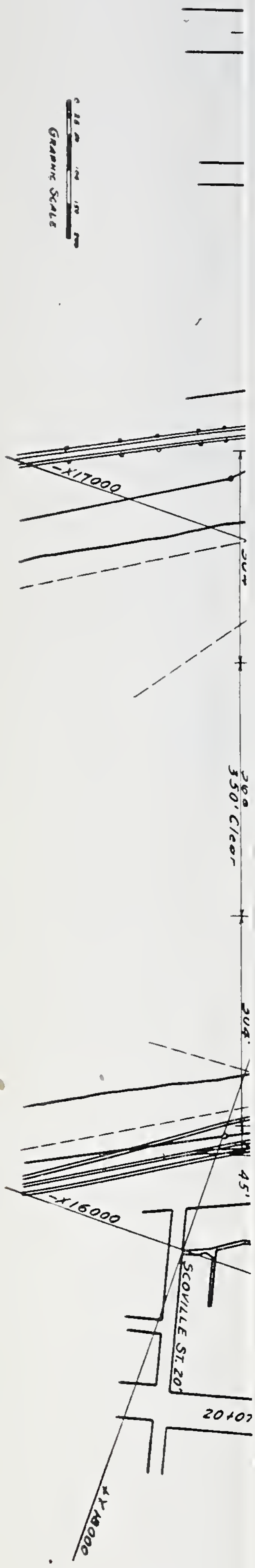
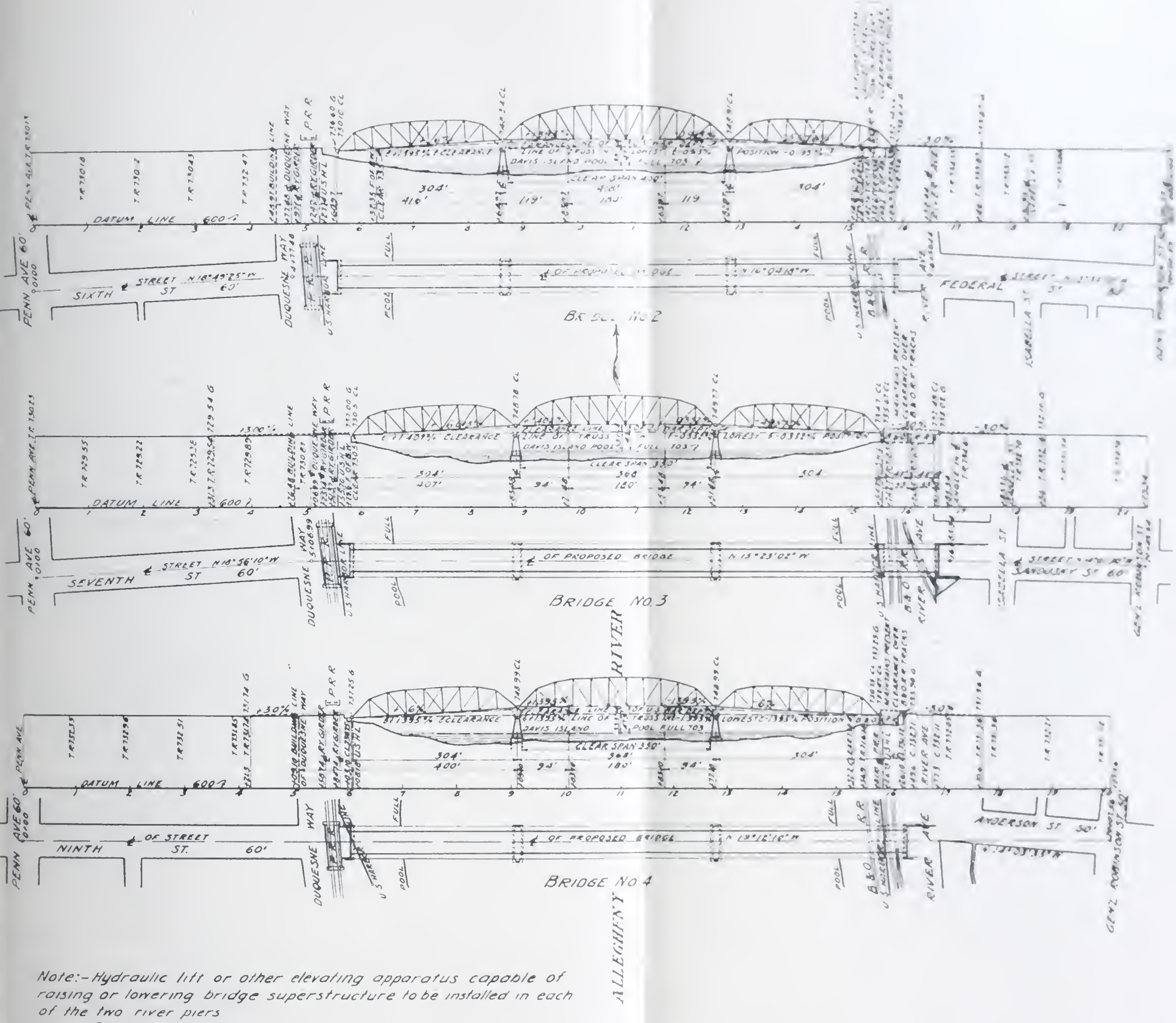

GRAPHIC SCALE
-X17000
350' Clear
45'
-X16000
SCOVILLE ST.
20+07
+Y18000

Fig. 4



Note:- Hydraulic lift or other elevating apparatus capable of raising or lowering bridge superstructure to be installed in each of the two river piers.

Bridge to be operated in such manner as to maintain a clearance of 33 feet above water, for a linear distance of 180 feet at central portion of center span during all stages of water not exceeding the 20 foot stage.

Fig. 6. Profiles Illustrating Use of Continuous-Traffic Lift Bridges

Fig. 4

DISCUSSION

Mr. C. M. Reppert:* In the reconstruction of the three Allegheny River bridges the public is interested in the following important points:

1. The cost of the river spans as reflected in taxation.

2. The adequacy of the bridges, with respect to provision for required capacity and speed of traffic.

3. The grade of the approaches and of the bridge floor as restricting the free movement of traffic and the loading of vehicles.

4. The cost of approaches, the damages incurred thereby, and the resultant effect upon the grades, traffic, and business conditions on streets affected.

5. A reasonably clear channel for the operation of river craft at all times when river navigation is feasible.

6. The proper planning of the bridges with respect to possible development of the wharf by means of dock walls or other structures, and the effect upon new thoroughfares located along the river fronts.

These are all most important questions and worthy of the most thorough consideration and should all be settled to the general satisfaction of the community before definite plans are finally adopted.

As to the first of these points—that of the cost of the river spans—the technical study of the problem lies in the hands of the county commissioners and the paper of the evening presents a most interesting solution, provided the solution it offers at the same time answers the other requirements.

As the life of the proposed bridges will cover several decades, the adequacy of the structures with respect to width of roadway

*Chief Engineer, Bureau of Engineering, City of Pittsburgh, Pittsburgh.

should be checked carefully with present and future traffic requirements, particularly the development of new outlets, the growth of warehouse districts and like matters. Lack of width of roadway may easily restrict growth of an important section of the city or discourage through traffic in such a way as to restrict the development of the whole community by intensifying, at greater expense, development of other sections. The comparative advantages and economy, particularly the saving in a deferred investment of building an additional bridge or bridges at some later time when traffic conditions warrant, should be compared with the cost of widening the roadway of any of the present bridges.

Grade lines are most important—in the first place, in creating obstructions to traffic in many ways. If the grades are too heavy, interruptions to traffic are likely to occur, dependent, of course, upon the character and volume of the traffic and the nature of the pavement, and also upon the number of traffic lines. There must be a certain relation between the cost of obtaining a certain gradient and the usability of the roadway with respect to traffic—in other words, a truly economic gradient. Minimum grades on a bridge are subject to somewhat different conditions from those on a bridge approach or highway, for the reason that the roadway surface is more subject to sudden freezing and excessive slipperiness.

The plan for the movable bridges shows that a grade of six per cent. will be imposed during periods of extreme high water. Very careful consideration should be given to this feature before the plans are adopted. The possible restriction and inconvenience to traffic should be compared with the saving effected by the proposition.

A most important requirement, if the lift type is adopted, is that the break between the six per cent. and the 1.4 per cent. grades be accomplished by means of a gradual vertical curve, as a sudden break in grade leads to serious accidents. The permissible gradient of the bridge should not be based upon the now prevalent types of bridge pavements, such as asphalt, asphaltic concrete, and wood block. Brick pavement, including beveled

brick and various types of block stone can be considered, and the limiting gradient thereby raised. The serviceability of these pavements combined with maintenance and special treatment during slippery weather may be further considered.

The cost of the approaches is to be considered under two main headings—first, the physical cost, which generally is not the most important factor; and, second, the damages incurred thereby. The plans for the fixed bridges, conforming to the War Department requirements, would impose very considerable damages due to raising of the grades of approach streets which generally have high value and are improved with costly buildings.

The required changes in the Duquesne Way elevated railroad of the Pennsylvania Railroad Company would be very great and the legal questions involved should be carefully considered. The grades imposed on the approach streets by the fixed bridge type are not excessive. Incidental costs of changing the grade of Duquesne Way throughout so as to provide a future broad highway should also be considered.

The necessity for including the planning of the bridges in the general planning of the down-town district is clearly indicated, in order to build the city in conformity with a wise and economic program.

MR. RICHARD KHUEN:* This discussion will be confined entirely to the practicability of this scheme from an engineering standpoint.

The longest structure to be dealt with is the Sixth Street crossing—one 418-foot channel span and two 304-foot spans, one at each end of the channel span; the 418-foot span to go up in a horizontal position and the 304-foot spans to be tilted. The total height to be lifted is 14 feet. In order to arrange properly the expansion, due to temperature, the structure will have to be fixed on one of the main piers with expansion arrangements at the other pier and at the abutments. The 14-foot lift on the piers will cause a slight movement at the shore ends of the 304-foot

*General Manager of Erection, American Bridge Co., Pittsburgh.

spans. The design of these ends can be so arranged as to make this opening negligible. The main opening will be due to temperature expansion, which will be the amount due to 722 feet of steelwork at one end and 304 feet at the other. This is not at all unusual and no doubt a proper expansion joint in the floor can be arranged. As far as the piers in the river are concerned, it may be necessary to increase the width of the pier slightly at the fixed point to take care of the total longitudinal forces but this increase will undoubtedly be small.

The total load on each of the main river piers would be about 2800 tons, which includes, of course, an allowance for live load. While several methods of raising can be devised, I believe the best arrangement would be two hydraulic jacks on each pier, directly under the line of the trusses, these four hydraulic jacks to be placed in an inverted position so that their bases would be attached to the movable span and all jacks operated from one hydraulic pump placed in the power-house in the middle of the main river span above the required clearance line of the traffic. These four jacks must be automatically controlled so that they will raise the span uniformly at the four points. This can readily be done by automatic cut-offs, which will shut off the water from any one of the jacks which has a tendency to move ahead of the others. Based on an ordinary working pressure of 3000 pounds and a maximum of 4000 pounds, the plungers of these jacks will be about 32 inches in diameter, and the cylinders about 48 inches in diameter The run-out of the jacks will have to be 14 feet, which will make the construction of the cylinders somewhat difficult, but this can doubtless be successfully accomplished. It is, of course, understood that at the fixed pier these jacks can have ordinary square bases, but at the expansion pier they would have to be carried on pins or trunnions so as to allow for the expansion of the span.

It is manifest that after the spans have been lifted to the desired height, some arrangement should be made to carry the load, so that the jacks could be relieved, as it would not be advisable to carry the load on the water for any great length of time. This could readily be done by placing screws as close to the jacks as practicable at the four points. These screws could be operated

by power and their only function would be to act as a follow-up for the jacks, so that the load could be transferred to these screws whenever the span reached the proper height. The screws, therefore, would carry only a static load and would probably be from 18 to 20 inches in diameter. They could, of course, have square bases at the fixed pier but would have to be carried by pins or trunnions of some kind at the expansion pier. This presents no unusual difficulty.

So far, we have taken care of raising the bridge and carrying the vertical loads only. In order to provide for the horizontal forces, both transverse and longitudinal, it will be necessary to have short guide towers at the ends of the two piers and adjacent to the trusses, these guide towers to be built into the piers practically forming a component part thereof. They would, of course, be made of steel. The method of taking care of these forces by projections from each span to these towers presents no unusual difficulties, it being understood that the total longitudinal force would have to be taken care of by the towers on the fixed pier. It is obvious that these towers would not have to be very high as the total vertical movement of the spans is only 14 feet.

If thought desirable, an emergency hydraulic jacking outfit can be supplied at a low cost; namely, one pump and four jacks of the proper capacity with about a two-foot run out for emergency purposes. These jacks could be used on blocking in the usual manner in jacking up spans in case the pump or the main jacks fail.

If it is thought desirable or economical to decrease the size of the jacks, this could readily be done by partially counterweighting the spans. This would make the towers at the two ends of the main river piers considerably higher and would probably make it more difficult to give the structure a proper architectural appearance. The details would have to be worked out before this could be determined.

Inasmuch as the time given me for this discussion has been very limited, I can give only approximate ideas of the size of jacks, etc., but from these results I believe the scheme is entirely practicable from an engineering standpoint.

Major J. F. Bell:* Mr. Henderson has presented a very interesting paper on a subject of live interest. Before discussing his plan it seems advisable to set forth more specifically just what the orders of the Secretary of War require.

The Orders of the Secretary of War. The Secretary of War has issued orders that certain bridges across the Allegheny River, including those at the Sixth, Seventh and Ninth Street crossings, Pittsburgh, be altered so as to permit free and unobstructed navigation on that stream.

These orders were issued after exhaustive examinations and hearings had demonstrated that the bridges in question are an unreasonable obstruction to the navigation of the Allegheny River and that their immediate elevation and the relocation of their piers are necessary in the national interest.

Congress, in appropriating money for the improvement of the Allegheny River in 1913, made its expenditure dependent on the assurance that the bridges would be altered in compliance with a previous recommendation by a Board of Engineers. The alterations in elevation ordered for these three bridges are briefly as follows:

1. The Sixth Street bridge is to be raised 1.8 feet at the Pittsburgh end, 1.6 feet at the Allegheny end, and 13.7 feet in the middle.

2. The Seventh Street bridge need not be raised at either end, but must be raised 12.6 feet in the middle.

3. The Ninth Street bridge must be raised 0.4 of a foot at each end and 14 feet in the middle.

Each bridge is to have three spans. Details will not be given as they are not pertinent. The problem under discussion, then, is what type of bridge to build to comply, in effect, with the above orders, and provide the most satisfactory crossing for traffic.

Solutions. Mr. Henderson has presented a very ingenious and interesting solution of the problem. As stated by him, he

*U. S. Engineer Office, Pittsburgh.

proposes a lift bridge, with a vertical lift in each pier. By this arrangement, the center span would be raised vertically, and the shore spans would have their river ends raised vertically, provision being made for the shore ends to slide or roll in a horizontal plane.

In considering Mr. Henderson's method, it is desirable to have some other solution with which to compare it. The simplest and most obvious solution is the one in which each bridge is raised only sufficiently to comply with the orders of the Secretary of War as outlined above. For convenience in reference, let us refer to this as the "standard plan".

Assuming the center section 180 feet long in the standard plan to be level, both end sections of the Sixth Street bridge would have grades of 4.35 per cent.; the end sections of the Seventh Street bridge would have grades from 3.85 to 4.93 per cent.; and the Ninth Street bridge from 5.1 to 5.7 per cent. The cost of the approaches would be negligible. If a deeper floor system be constructed than exists at present, the grades would be increased somewhat or the approaches raised correspondingly. We can assume, therefore, a maximum grade, in the standard plan of about five per cent. with very little change in the approaches.

Advantages and Disadvantages of the Henderson Plan Compared with the Standard Plan. No plan has yet been submitted to the War Department for approval. The Chief of Engineers has stated to the county engineer that if plans for the Henderson lift bridge be submitted, plans complying strictly with the orders of the Secretary of War should be submitted at the same time with details of the advantages and disadvantages set forth, so that the matter may receive full and careful consideration. Some of the points that should be covered in such a discussion are set forth below.

Certainly Mr. Henderson's plan should be and will be met with minds open to conviction that it is the best possible solution. The questions asked here are not presented in the nature of arguments for or against the plan. They are questions that must be

considered in arriving at a conclusion as to whether it is the best solution of the problem.

1. Why is a grade of over three per cent. intolerable?

The grade on the bridge where the Boulevard of the Allies crosses the Pennsylvania Railroad is five per cent. The Bloomfield bridge is a very long, much used bridge with a grade of four per cent. The approaches to the North Side, Point, and Smithfield Street bridges are from 4.25 to five per cent. Many streets here have grades of from 5 to 15 per cent.

2. How much money will be expended for additional power per day if the standard type bridge is built instead of the Henderson lift type?

It costs about half a cent for enough gasoline for a truck or automobile to cross one of these bridges. How much more gasoline will be used if the shore spans have a five per cent. grade rather than a 1.5 per cent. grade? If a 25 per cent. increase be assumed, the traffic count made by the City Planning Commission would indicate an increase in cost for power per day for the three bridges combined, of about $15.

3. What traffic is there across these bridges that does not have to be powered high enough to make a five per cent. slope elsewhere? Are many trucks in Pittsburgh loaded so heavily that they cannot make a five per cent. grade?

4. What installations and machinery will the Henderson lift bridges have? How much will they cost? How much should be estimated for depreciation, maintenance and operation, and interest on investment?

5. How reliable will the lifts be?

Elevators get out of order; so do ordinary drawbridges. Lifting heavy trusses on jacks is a rather delicate operation. It is here proposed to lift a horizontal and two inclined trusses in all kinds of weather, with varying snow and moving loads, and with eccentric loading due to varying wind pressures. Operation is menaced also by the possibility of a pier settling out of plumb,

or being moved or inclined by the effects of flood or ice or a blow from a steamer or heavy barge.

If one of the six lifts be out of commission, the river will be blocked. Suppose then, for the sake of comparison, that an elevator or lift is in operating condition nine-tenths of the time.

In an office building, served by six elevators, the probability that at least one elevator will be running is $1-(1/10^6)$ or 999,999 chances out of a million. Under the same hypothesis, the probability of all these six lifts being in operation so that boats can pass when a higher elevation is required is $9^6/10^6$ or 531,441 out of a million or only about 1 chance in 2.

6. Why not build one bridge in place of the two at Seventh and Ninth Streets?

The total traffic over the two brdges is less than that over the Sixth Street bridge. Perhaps such a bridge could be built with approaches along Duquesne Way so that the grade both on the bridge and approaches could be kept to about three per cent. It would appear desirable to divert the traffic along Duquesne Way if possible, rather than conduct it into the congested district in the interior of the triangle.

7. What other advantage has the Henderson plan over the standard plan? Is there more probability of accident on the bridge or under the bridge in one case than in the other?

Conclusion. As stated by Mr. Henderson, many plans for drawbridges are approved by the War Department every year. In many cases, it is the type that best fulfills the needs of the situation. The question now is whether the advantages of the Henderson type of lift bridge outweigh its disadvantages, for construction over the Allegheny River at the above crossings.

Mr. E. K. Morse:* The subject of the evening has been pretty well covered. I am going to eliminate everything for the time being except two points which I consider the crux of the case.

When the present Sixth Street bridge was under considera-

*Consulting Engineer, Pittsburgh.

tion to take the place of the old suspension bridge that was there, I was acting as consulting engineer for the late John R. Jackson, president of the Sixth Street Bridge Company, and of the Fidelity Title & Trust Company. Competitive designs were called for and the successful plan was laid before the Pittsburgh Coal Exchange and the government for approval. The Pittsburgh Coal Exchange opposed it to the limit and disapproved of plans that were then identical with the ones now suggested by the War Department, with the exception that the height was less. The present height was under consideration then and the clear height above full pool that now exists was then approved and adopted. The representatives of the Pittsburgh Coal Exchange said they would not accept a channel span for the Sixth Street bridge, and that they wanted two channel spans with a pier in the middle of the river.

Mr. Jackson asked me to pick out one of the best bridge engineers in the United States to act as consulting engineer and I suggested Theodore Cooper. Competitive plans were again received and Mr. Cooper's plans were accepted and the bridge now built, the present Sixth Street Bridge, is the one Theodore Cooper designed and the one approved by the Pittsburgh Coal Exchange and the one accepted by the engineers of the War Department and the Secretary of War at that time. It is exactly what the Coal Exchange wanted; yet in less than ten years from the time it was erected the Coal Exchange wanted to change the span to just what the War Department is now advocating.

I mention this for a purpose. In most of the cases in this vicinity, I regret to say that the government has coincided with the river interests. In many cases I am satisfied it was not to the advantage of navigation. I think it was a mistake when the government made the owners of the Union bridge, across the Allegheny River at the Point, take down that wooden bridge at their own expense and pay $15,000 in addition to the salvage. And then what did they do? Built a pier right in the middle of the channel! I do not know that I shall live to see this new bridge rebuilt to satisfy the whims of navigation, so called, but I believe that some of you in this room will see that bridge taken

down. I believe the time will come when the pier in the middle of the river will be declared a menace to navigation.

Now we come to the point of the government reversing itself. The government now asks that the Sixth Street bridge be taken down. That method of doing business is most unbusinesslike. This brings up the correlated question, which is just as important to navigation as to the traffic over the bridge. Before the approval of the Sixth Street and Ninth Street bridges by the government, the whole subject of river terminals should be analyzed with it. Do not be suprised if I should take sides in the very near future with the canal to the lakes. That has been a very lukewarm subject with me but since the World War and the falling down of our transportation facilities my viewpoint has entirely changed on the subject of traffic for this vicinity. We must have better facilities. I have no criticism of the railroads, but their facilities are not adequate to the growth of the community. Every study I have ever made of the question of traffic (and there is not a section leading out of this vicinity to the northwest that I have not surveyed, trying to get another railroad into the city of Pittsburgh) indicates that improved wharf terminals, the building of a canal, and the improvement of our river channels, must come in order to keep pace with competitive districts. When I began studying the question of traffic as Transit Commissioner for the city of Pittsburgh, four years ago, Pittsburgh stood fifth from the top. To-day it is twelfth. Why? Because a community grows in direct porportion to its facilities to handle traffic.

The War Department is in error in one prominent feature with respect to the raising of bridges, and that is in assuming that the navigable height should be carried to a 20-foot flood stage. That assumes that the locks are not to be used at all. Long before that height is reached there is no navigation in the Allegheny River; furthermore, the locks at Dam No. 1 in the Allegheny River cannot be operated in a flood over 18 feet. I will cite just one case. You all know that when you make a mistake and pay for it out of your own pocket your memory is always fresh on that subject. When I was erecting the Ninth Street bridge, Captain Charley Hook was hired to hold his boat below the Ninth Street bridge for

emergencies. On May 24, 1891, a derelict barge came down the river and struck the trestle in the channel span. Every brace was knocked loose. That happened about seven o'clock in the morning. Word was sent to Captain Hook to swing out into the channel and save that trestle if possible. He said he wouldn't do anything of the kind. I went to him and said "What is the matter? I pay you $100 a day to lie here for emergencies of this kind." He replied "No damn fool of a pilot would navigate the Allegheny River in a flood." I said "What do you mean?" and his reply was "I am not going to go out there and wreck my boat." He floated down the river and tied up on the Monongahela River wharf.

The height of the water at that time was 16.5 feet. At three o'clock the last pile in the trestle snapped and everything was lost. That afternoon the river rose to about 24 feet and ran with unusual swiftness even for the Allegheny, which is always dangerous at flood time.

The difference between 16 and 20 feet settles the question of grades in the approach to the bridges. If it were split in two, the question of grades on the approach would be very much simplified, because every foot added to the approach to these bridges is vital. I can not conceive of changing the grades in either city. Mr. Henderson has, to my mind, submitted the best plan for the solution of this subject, but it is a question of the most vital importance that the hoists, if they are adopted, be made so that they cannot fail. For that reason I would double the number of jacks, and double in every case I could, so that if one did go bad the other could be put into immediate action. Furthermore, action should be automatic. I would condemn the system if it depended on human manipulation for its control.

In the Act passed March 23, 1906, which was a modification of the old Acts of 1873 and 1883, for the Ohio River bridges, Section 3, Item 26 reads as follows:

"No bridge erected or maintained under provisions of this Act shall at any time unreasonably obstruct free navigation of the waters over which it is constructed, and if any bridge erected in accordance with the provisions of this Act shall, in the opinion of the Secretary of War, at any time unreasonably obstruct such navigation, either on account of insufficient height, width of span, or otherwise, or if there be difficulty in

passing the draw, opening, or draw span, of such bridge by rafts, steamboats, or other water craft, it shall be the duty of the Secretary of War after giving the parties interested reasonable opportunity to be heard, to notify the persons owning or controlling such bridge to so alter the same as to render navigation through or under it * * * free, easy and unobstructed."

That means that every highway bridge over the Allegheny River would, if it were so ordered by the Secretary of War, have to be taken down. Even the Sixteenth Street bridge, now building to suit the Secretary of War, and built to meet the whims of navigators, can be ordered removed if for any reason the Secretary of War should again determine that it is a menace to navigation.

The whole wharf subject should be taken up, the wharf lines ignored as now laid out, and new wharf lines drawn in the interests of terminals, and every street along the Allegheny River approaching the wharf should be a one-way street. The subject should be studied exhaustively before any more decisions are made by the War Department. The Pennsylvania Railroad has no right to be on the Allegheny wharf. It is antagonistic to the civic beauty of both cities; it is against the interests of navigation; it is against their own personal interest.

I hope to see a wharf built in a straight line from the Point to Eleventh Street or above the Ninth Street bridge and brought up above flood height, at least to 33 feet. If that is done, Mr. Henderson's plan is not necessary; and, if that is done, the city should vacate all the streets from Penn Avenue to the Pennsylvania Railroad and from the Union Depot to Thirty-third Street thereby making one grand railroad terminal. Then there will be no elevated railroad along the Allegheny River; then there will be the city beautiful; then there will be a city with river terminals; then will the bridge problems be solved.

Mr. C. A. Finley:* I have listened to the discussion of the lift bridge and the stationary type of bridge and the thing that is most impressed on my mind is that the conditions laid down in the order of the Secretary of War as to elevations are just a little more than sufficient to involve the city in serious grade and

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grade damage problems. A few feet lower and we could establish grades that would not seriously affect us. The fact that these few feet are involved is what gives rise to the consideration of movable bridges.

I confess that I can not regard the five or six per cent. grade on these bridges with the same equanimity that Major Bell does. It is not so much a question of traction as it is of bad traffic conditions obtaining, especially in winter on the kind of paving which it is desirable to use on bridge floors. A three or 3.5 per cent. grade can be operated effectively even in slippery weather, but five or six per cent. grades with rain and freezing weather offer much opportunity for traffic delay. I have seen traffic on Grant Boulevard, which is a six per cent. grade, tied up 20 minutes by a sleet storm that froze on the pavement, so that it was an hour or two before they could get it straightened out. That is the thought that is in my mind on the steep grade proposition, rather than traction costs.

Mr. Morse has called attention to the fact that the problem involves more than the actual handling of the bridges; and it involves a broad study of wharf improvement and street and grade adjustment in connection therewith. He has also called attention to the fact that boats cannot be operated at the stage of water which the proposed new elevations are designed to accommodate, but apparently are compelled to cease operations when the stage of water is several feet less, not because of the bridges but because of the current. A modification of the requirements in bridge elevation to this extent or even a part of it would eliminate most of the elements of disagreement, and would permit the city to carry out its part of the development at a reasonable cost, with possibly no damage to river interests, present or prospective.

Mr. A. R. Raymer:* I came out to-night to get information and have not given this problem any particular study. I have been very much interested in the various views that have been presented. As far as the mechanical part of Mr. Hender-

*Chief Engineer, Pittsburgh & Lake Erie Railroad, Pittsburgh.

son's scheme is concerned, I am convinced the details can be worked out, if necessary. No problem is presented which is very much different from many which have been solved in connection with lift bridges.

I was also impressed by Mr. Morse's statement that the whole problem should be discussed and settled before any part of it is carried out. I think that is sound policy. While the wharves are under consideration, nothing should be done in the way of building bridges which would interfere with the best development of them.

MR. H. R. THAYER:* The grade of three per cent. that has been talked about is an extremely low maximum to be proposed for a town like Pittsburgh with its topographic conditions. It seems especially so to one who, like myself, slips down Negley Avenue every morning and clambers up every night. I note that in the possible solution they have used six per cent., and I feel sure that for the very few days when operation would be required it would work out all right.

Regarding the suggestion of our chairman concerning the vertical curve, more than 98 per cent. of the time the bridge would be practically level. In this position the curve would be a disadvantage.

The speaker of the evening brought out the four possible methods of crossing a navigable stream—boat, tunnel, low bridge and high bridge. The method of boats would not be considered in a location like this where a bridge is a possibility and where we have to carry a large traffic. The tunnel would seem to be unsuited to our topographical conditions. The low bridge with the ordinary movable span would be extremely expensive or else a great hindrance to navigation. The high bridge seems the only one of the four that offers a reasonable solution. The speaker of the evening has advocated a type which so far as I know is rather new—a distinct contribution to engineering literature. These two solutions are before us for very serious consideration. The continuous-traffic bridge is practicable, but it will demand an im-

*Markhart-Thayer Engineering Co., Pittsburgh.

mense amount of study before we can venture to offer it in a practical way. I cannot agree at all that it is a matter of an evening to design and I shall present my idea of some of the troubles you will be up against when you attempt to deal with this question of design.

This way of handling a bridge is somewhat similar to the type already known as the vertical-lift bridge. Until a few years ago, it was used very little, and entirely in short spans. The method of handling large weights has not been fully developed, and the hydraulic lift is not a thoroughly dependable method. It will work, but it is likely to fail at critical times. The first thing is the question of bracing. When a bridge is to be raised to a height of 14 feet it necessarily must be braced longitudinally and transversely, and that bracing must be beyond all criticism. You are handling very large loads and you must not have weakness in any direction. I believe it should be fixed at both ends with an expansion joint in the middle. That would leave something that would brace the entire structure. Furthermore, it must have transverse bracing. I do not believe it would be practicable otherwise to resist possible wind pressure and transverse forces.

Another question is that of counterweight. When you counterbalance a weight of 1400 tons at each corner of the bridge you run into considerable difficulty both in regard to the design of the machinery and in finding a place for the mass that would have to be provided. The whole matter of designing the power on the various parts would be a little bit beyond anything that has been attempted thus far. About the only parallel of which I know is the raising of the center span of the Quebec bridge and the experience the engineers had there would not be of the kind that would make us feel like treating this problem trivially. While it can probably be successfully handled, I believe it will demand a great deal of very careful study.

Mr. H. D. James:* The Mechanical Section is to be congratulated on the paper of the evening. I am glad to see members of our Society taking an active interest in engineering matters

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affecting Pittsburgh. I strongly recommend that engineers take an active interest in public affairs, particularly matters of an engineering interest. Our Society has a membership of fourteen hundred engineers who should be thoroughly informed on public matters of this kind so that they can exert their influence in the right direction. Questions of an engineering nature can usually be settled if all of the facts are available.

MR. J. P. LEAF:* In the building of this permanent dam to take the place of the Davis Island dam you have a real harbor question. I can see boats distributing cars from the different railroads to the various works along the rivers and going up to a great terminal that we can get on land. It seems to me that, if we are only two feet apart in elevation, Pittsburgh ought to be able to comply with these conditions, or the government to meet them half way.

I like Mr. Morse's remarks concerning high water. Pittsburgh is not improving as other cities that have navigable water have improved in the last ten or twenty years. If you look at the cities that have improved above the average in the United States, in nine cases out of ten they are on improved rivers, or the Great Lakes. We should develop our rivers, we should develop our roads, we should develop our railroads. Pittsburgh has the best railroads in the world, but I do not hesitate to say that we are discriminated against in railroad rates. We always have been.

MR. WINTERS HAYDOCK:† Major Bell, in his discussion of the paper of the evening, has touched upon some very interesting questions, some of which I had come prepared to bring up myself. One of these is the question of economics involved in the additional rise which would have to be overcome by traffic using the bridges as rebuilt in accordance with the present order of the War Department. How serious from an economic point of view would this additional rise be, and how much could we afford to spend solely for the purpose of eliminating it?

*City Engineer, Beaver Falls, Pa.

†Chief Engineer, Citizens Committee on City Plan of Pittsburgh, Pittsburgh.

An answer to this question cannot be worked out with any degree of exactness, as a great many elements of guesswork would enter into the solution; but perhaps we can work out a method of guessing in a rational way. Certain writers have gone into the matter of the additional operating cost of rise and fall in vehicular thoroughfares. One of these is Mr. Wilson G. Harger, writing in *Engineering News-Record*, July 22, 1920.* Using his methods of analysis and assuming an average cost for fuel per mile per vehicle of 2.7 cents, we find the additional cost for fuel for each extra foot of rise to be about $50 per year for each 1000 vehicles per day of traffic density. This figure is probably a maximum. If the additional rise is 14 feet, this additional cost for fuel becomes about $700 per year for each 1000 vehicles per day. The traffic count made in 1920 by the Citizens Committee on City Plan showed a total of 12,321 vehicles passing over the three bridges in question in 11¼ hours. If we assume that within the near future the daily traffic over these bridges will reach 20,000 vehicles, the cost of fuel chargeable to an extra rise of 14 feet might become $14,000 per year. When the traffic reached 30,000 vehicles per day, that charge might become $21,000 per year.

We should not, of course, attach too much importance to such figures, but they serve to indicate that for the sole purpose of saving fuel, we are probably not justified in spending a very considerable sum to avoid the extra rise, especially if the extra yearly operating and maintenance costs are to absorb a considerable portion of that saving. But there are other reasons why we should strive to eliminate all unnecessary rise in these bridges. For example, the necessity will exist for stopping traffic on the descending grades at the ends of the bridges on account of the movement of traffic on cross streets. Under such circumstances it would be safer in slippery weather not to have grades as high as 4.5 or 5 per cent.

Major Bell brought up the question of the basis of limitation for the rate of grade on these bridges. Is it necessary to confine ourselves to a three per cent. grade? I have drawn up a pro-

*v. 85, p. 171.

file which indicates that it is possible to get a grade of 4.5 per cent. on the Seventh Street and Ninth Street bridges, and a grade of 4.35 per cent. on the Sixth Street bridge without any very serious changes of grade on the approach streets. This is based on the assumption that we can get along with a floor system only 5.5 feet, thick. I am of the opinion that by careful attention to the details of design we can get within the 5.5 foot limit without seriously affecting the rigidity or the weight of the structure. This question of the allowable maximum grade should receive careful consideration.

I wish to endorse what Mr. Morse and others have said about the necessity of considering the future development of the river front. It does not seem conceivable that Allegheny County will complete plans for the reconstruction of these bridges, which ignore the possibility, or rather the probability, of a quay wall being built in the future at a considerable distance out from the present ends of the bridges.

In closing I wish to ask Major Bell a question and if it embarrasses him he will please says so. Several years ago one of the army engineers made a report on the raising of the bridges in which a clearance was recommended which was four feet less than the clearance required by the present order. I wish to ask whether in his opinion it would be reasonable for Pittsburgh and Allegheny County to ask the War Department to reopen the question of clearances, confining the investigation to the question of reducing the clearances by about four feet. I believe that if this reduction could be brought about, the difficulties of this situation would be at an end.

MAJOR J. F. BELL: I am not embarrassed in the slightest by the question. I will start by saying that I am heartily in sympathy with this plan of developing the terminals in the Pittsburgh waters. I made my first speech in favor of that before the City Planning Conference a year ago.

Although I do not agree with some of the rivermen in this district, I am convinced that any hydraulic engineer can satisfy himself that by a little dredging in the river you can compensate for any cross-section you take up on the banks.

As for a change in the required elevation of 47 feet above pool level, as specified in the order of the Secretary of War, Gen. Beach has said that he is willing to consider anything that the city has to advance in the way of modification that might relieve them of difficulties; and it seems to me entirely feasible, if the county so wishes, that when they submit their application to construct these bridges, as ordered by the Secretary of War, they also put in modified plans in the same way that has been suggested. If they show good reason why a two-foot difference in elevation should be approved, it will be entirely proper to submit it. As for entering into an agreement or arrangement with the War Department with regard to delay in getting up your plans, I do not see that an agreement is in any way necessary. Why not go ahead and make your plans? You know perfectly well that as long as proper progress is being made there will be no trouble. There is nothing to keep you from going ahead and making your plans for the waterfront also. If you are working to that end (and I think it is highly desirable that these problems should be solved—terminal, traffic, and bridge problems together) I am sure it will meet with every encouragement.

Mr. L. P. Blum,* As retiring Chairman may I express my appreciation of all of the contributions to the program of the evening. There are many phases of this question brought out by the discussion, but I shall confine my discussion to the single question of grades on the city streets with reference to these bridges.

For every-day continuous use, I believe that no grade in excess of three per cent. should be considered. Grade is a matter of environment. Grades in the down-town district of a busy city must be determined on a different basis from the grades of Negley Avenue and other residence streets. We have a busy down-town district around the rivers with access to practically all of our freight stations and in this district three per cent. is approximately the limiting grade. To introduce heavier gradient in this area would be comparable to putting a one per cent. gradient in a railroad line which has been standardized for a long

*Blum, Weldin & Co., Pittsburgh.

distance with one-half per cent. limiting grade. It is no answer to say that other railroads operate on higher gradient.

Mr. Haydock has touched upon the difference in expense involved. It is not a question of the cost of the gasoline; it is a question first of all, of safety, then of the capacity of the bridges and of effect on real-estate values. While any truck operating in Pittsburgh could possibly haul any legal load on grades in excess of three per cent., its speed would be cut down, and such reduction of speed of vehicles decreases the carrying capacity of our bridges. Every street grade increases traffic hazards, especially in congested areas. As to the effect on real-estate values, we have spent millions of dollars in cutting the Fifth Avenue "hump", and have found the expense amply justified in the increased real-estate values developed in the district affected. It is the opinion of prominent real-estate men whom I have interviewed that any separation of the North Side from central Pittsburgh by the introduction of bridge grades is bound to have a detrimental effect on property values in both of the areas involved, and this effect, will probably be in approximate proportion to the rate of grade of the bridges.

Considering, therefore, all of the above conditions, I have no difficulty in coming to the conclusion that a continuous-lift bridge of the type described by Mr. Henderson is preferable to a bridge with permanent but steep approaches. The comparison is that of a practically level grade for 10 months in the year, with grades of six per cent. on very rare occasions as compared with the permanent inconvenience of a three per cent. grade the establishment of which will cost either the city or county millions of dollars in damages for change of grade.

Are we certain that this raising of bridges will be required in future years?

In *Engineering News-Record* of Feb. 2, 1922,* there is a paper discussing this very subject with relation to a bridge at Bismarck, N. D., and traffic conditions on the Missouri River at that point. Prior to the World War, due to use of coal-burn-

*v. 89, p. 180.

ing equipment on river packets, the tall smoke-stack was necessary and a clearance of 50 feet was required. Since the war all of these packet lines have found it necessary, in order to continue their competition with the railroads, to change to internal-combustion engines; and according to this article this change has decreased the clearance necessary on the Missouri River from 50 to 38 feet, as allowed by the United States Engineers. Is there not a possibility that a similar modification of motive power may be developed which is suitable for the control of flats on our rivers? Such a possible development furnishes another argument in favor of the continuous-lift bridge.

Mr. A. A. Henderson: Any person interested in the development of the type of bridges proposed will appreciate the constructive criticism offered by Major Bell.

He suggests that the various points he mentions should be given consideration in case a bridge of proposed design should be submitted to the War Department for approval. Since there is a possibility of the local authorities asking such approval, any extended reply to Major Bell's questions at this time might be considered premature.

In presenting the subject I have accepted the final opinions evolved from various hearings as conclusive; namely:

1. The fixed grades on bridges should not exceed a maximum of three per cent.

2. The necessary clearance for water craft is 33 feet, and should be available up to the 20-foot stage.

I feel that we cannot question one conclusion without the right to question the other also. I have questioned neither.

Two factors which contribute to the discrepancy between the five per cent. grades suggested in Major Bell's paper and the six per cent. temporary grade of tilting spans, are:

1. The United States Government assumes that new bridges, in each case, will have the same depth of floor system as the existing bridges. Allegheny County has concluded

that conditions require at least 6.5 feet for depths of the floors in new bridges. These two methods of estimating depth of floor system produce a variation of 46 inches at the Seventh Street bridge, where the present floor system of the suspension bridge is only 32 inches in depth.

2. The plans of the United States Government continue the grade of shore spans into the channel span, making a uniform grade from the abutment to a point within 90 feet of the center of the bridge.

In the proposed lift bridge, the grade in the channel span does not exceed 1.4 per cent., which results in a six per cent. grade in the tilting spans when the bridge is raised to the highest position.

As regards the possibility of piers settling out of line, we should take into consideration that rock foundation will probably be reached at a depth of not over 30 feet below pool level. Numerous wells sunk along Duquesne Way, from Sixth Street to Ninth Street, indicate a continuous rock floor at about the elevation mentioned.

Mr. F. L. Egan:* If it is necessary to have the clearance ordered by the United States Engineers, Mr. Henderson's continuous-traffic lift bridge can be built, and it can be made to serve the intended purpose in a reasonably satisfactory manner. The raising and lowering of the bridge is a much simpler problem than some of the hydraulic canal-boat lifts, which have not only been able to operate satisfactorily, but have also proved a commercial success.

The canal-boat lift at Les Fontenelles, France, on the Neuf-fossé Canal, is capable of lifting boats of 300 tons. The lock chambers are 130 feet long, 19 feet wide, and 7 feet deep. Each of the two chambers is set upon the ram of a hydraulic lift. The ram supports a total weight of 800 tons, has a diameter of six feet, six inches, and a stroke of 43 feet. As one chamber moves

*Engineer, Pittsburgh.

up and the other moves down, there is a total weight of 1600 tons in motion.

The canal-boat lift at La Louvière, Belgium, has lock chambers 141 feet long, 19 feet wide and 8 feet deep. The rams are six feet 6¾ inches in diameter, with a stroke of 50 feet 6¼ inches.

The pressure is 470 pounds per square inch, and the time of operation is two minutes. The pressures employed are low, due principally to the long stroke making a large diameter ram desirable. Granting that the continuous-traffic lift bridge is practicable from an engineering standpoint, why should such expensive structures be built unless they are necessary? I am convinced that the clearance ordered is not necessary to safe navigation.

The War Department has ordered the three bridges raised, because of continuous pressure and complaint from the Pittsburgh Coal Exchange, and from men who were active in river transportation just before it died out. Most of these men believe that the bridges should be raised to accommodate the type and size of steamboat in use 40 years ago. They believe that when the bridges are raised, the Ohio River canalized its entire length, and Pittsburgh and all other cities on the Ohio River have built and equipped elaborate and expensive terminal facilities, then river men will build and operate steamboats of the type used 40 years ago. These men cannot or will not understand that, owing to higher fuel and labor costs, methods must change, and that the principal reason they failed in competition with the railroads was their own lack of initiative in lowering costs and increasing the speed of river transportation.

What I wish to bring out clearly is this—The engineers of Pittsburgh and of this Society should approach this problem as an engineering problem pure and simple and should disregard the mystery, cant, and erroneous advice of the reactionaries. I at present represent a project for river transportation between Pittsburgh, New Orleans and way points, which will require 10 modern boats of about twice the horse-power of our pool boats, to handle the tonnage we now have from interested shippers. These boats will move this tonnage considerably faster and at less cost than any operation we now have. The new boats will

have a maximum clearance height of 25 feet which could be lowered to 20 feet without hardship.

They will have the ability to operate and handle a tow in high water until the locks are covered. A fair percentage of our Pittsburgh boats are not safe and cannot handle a tow in a five-mile current. We have studied and plotted curves of the Ohio River navigation conditions prevalent for the past 20 years, and the equipment is designed to use the river, in its present condition, to the best advantage, and it will also be capable of increased tonnage as the Ohio River is improved.

We are not asking the United States Government to raise bridges and canalize the Ohio River, nor are we asking that Pittsburgh and other Ohio River cities build elaborate and expensive terminals. The project provides flexible temporary terminal facilities where necessary, but better terminals will be provided as a logical result when the traffic demonstrates what is actually required in the way of terminals. Adequate terminal facilities are not going to require as large an investment as most of the present schemes show, because a large percentage of the total tonnage available is heavy bulk stuff which shippers and consignees are preparing to handle at their own docks.

Let us expend our money wisely and use the Ohio River to a fair percentage of its present capacity. The United States Government will then complete the canalization of the river, because it will be a logical and justifiable development.

WATERFRONT IMPROVEMENTS IN THE CENTRAL BUSINESS DISTRICT OF PITTSBURGH

By E. K. Morse*

It is my intention merely to touch upon the following headings owing to the fact that they will be discussed by others:

History of Pittsburgh. History of transportation. Introduction of steam railroad transportation and its limitations. Pittsburgh's supremacy and future dependent upon transportation. Flood Commission's report on available power and navigation. River terminals. Traffic relations between rail and river transportation. Traffic relations between river terminals and truck transportation. Solution of problem by wharf construction. Wharf encumbrances.

History of Pittsburgh. The waters of the Monongahela River provide navigation to the South and those of the Allegheny to the North, with the two great overland routes over the Allegheny Mountains to the East lying between them. The Ohio River, with its tributaries reaching out into the Southwest, made its possession vital not only on account of the transportation facilities prior to any highways through solid forests, but as a protection to the pioneers. It was the key because it gave strategic control to navigation of these natural channels of transportation. Up until the time of the introduction of steam railroads after the Civil War, it was the cheapest and it can be made the cheapest to-day.

Few, if any, cities have their origin without a controlling reason for it. Pittsburgh got her start because of free river transportation from the head-waters of the Monongahela and Allegheny Rivers clear on down the Ohio River to Cairo.

History of Transportation. Navigation had much to do with the growth of Pittsburgh until about the early seventies, since when the gradual decay of river transportation has taken place

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until there is hardly a packet trade left—practically no through freight by regular steamboat lines, and were it not for the movement of a big tonnage of coal handled by private companies that mine and consume it the freight traffic on the Monongahela, Allegheny, and Ohio Rivers would be exceedingly small. The down-river towboats and all the paraphernalia that go with them have been moved down to the Kanawhas.

Introduction of Steam Railroad Transportation and Its Limitations. It is interesting to analyze the reasons why river transportation has given way to rail transportation. Among the many reasons, there are three that stand out prominently:

1. Rapid transportation by rail reaches the inland cities and towns. There has never been an interchange of freight between shippers by river and rail, but through no fault of the railroad. The navigators have scolded, and blamed the decay of river transportation on railroad companies but made no effort to locate the trouble and then correct it. They have gone on as their forefathers have done while the railroads have forged ahead rapidly taking all the business in sight.

2. The lack of adequate railroad terminals and the consequent long delays in loading and unloading caused serious congestion and car shortage in years past, and led the railroads to incorporate modern methods of handling tonnage by power. More and larger terminals are needed to-day, but car shortage through delay in loading and unloading is a thing of the past. Neither is there any excuse for such delays coming from private corporations, for practically every big shipper has equipped himself with up-to-date facilities. It is only the navigator who does things to-day as his great grandfather did a hundred years ago.

3. The cost of labor is an item of transportation to-day that makes it imperative in river traffic to handle every possible ton by power. In railroad transportation there have been great strides made in the building of engines and cars. In river transportation, at least in this vicinity, there has been practically no advancement during the last hundred years. The methods of loading the floating craft are for all practical purposes the same; the methods of receiving and dispatching freight are both by hand.

What railroad to-day could survive if suddenly called upon to use engines that could haul only one-half of the present load and freight cars that could carry only one-half the average tonnage now carried, and to load and unload by hand? It is too ridiculous to discuss, yet this is exactly the proposition of river transportation to-day. There are no facilities for receiving or dispatching freight for the public in Pittsburgh. There are wharf boats owned by certain packet companies that are struggling for existence. There are no modern wharves; there are no modern stationary or traveling cranes; there are no warehouses, and so long as this exists there will be no river transportation worth while.

Pittsburgh's Supremacy and Future Dependent upon Transportation. There are two packet lines operating from Pittsburgh down the Ohio River as far as Cincinnati. It is a common sight to see the wharf piled high with crates of poultry exposed to all kinds of weather. It is a wonder that the Health Department and the Society for the Prevention of Cruelty to Animals permit it, yet this is only one example taken from many. Expensive machinery, landed on the cobble-stone paving which is called our wharf, is allowed to stay there hours before loaded by hand.

Often a rise over night floods freight dumped out of a packet boat the evening before on the cobble-stone wharf. Is it reasonable to expect shippers to enthuse over such conditions? Could any steam road compete under such handicaps? Is it fair to condemn the whole subject of transportation by river when such conditions exist? When such conditions have existed for all time is this a progressive city? The answer is, emphatically, *No!*

Admitting that the timber has all been cut, that the oil and gas have come and gone, that there is no available coal for public use that would be handled by navigation; can anyone sanely argue in the face of such transportation conditions that Pittsburgh is not being starved, as it were, and its growth dwarfed on account of lack of transportation facilities? The size of our city and the growth that we should have, demand more and better transportation facilities. There can be no more intelligent growth of transportation facilities in this city until the terminals have been

greatly increased. This is one of the most serious of railroad problems and it is one that is confronting practically all the railroads in this vicinity. Pittsburgh never realized before as keenly as she does now, the meaning of "survival of the fittest."

Railroad transportation is not only unsatisfactory, but the cost is almost prohibitive. With the building of a few more locks and dams the whole waterways system will be completed on the Monongahela, up the Allegheny River as far as Kittanning, and down the Ohio River to Cairo. It is believed there will be a canal built at some point on the Ohio River connecting with the Great Lakes. Can anyone believe that this great system of transportation is destined to lie here idle while Pittsburgh is losing her supremacy in the manufacturing world for want of transportation? If so, then it will be the only place in the civilized world that such a thing has happened.

Flood Commission's Report on Available Power and Navigation. In 1912, the engineers of the Flood Commission of Pittsburgh published the most exhaustive report ever written, dwelling extensively on the question of navigation. Sites for numerous reservoirs on the head-waters of the Allegheny and Monongahela Rivers were located. Surveys were made showing the amount of water that could be impounded by the building of great dams with the primary object in view of regulating the flow of water during times of excessive floods to the extent of reducing the peak height of what otherwise would be a disastrous flood to a high water run-off producing little or no damage, interfering but slightly with the industries along the valleys of our navigable rivers. In times of extreme drought, water sufficient to operate the locks and dams on the Allegheny, Monongahela, and Ohio Rivers would thereby be provided. The question of power was merely touched upon but, since the publication of this report and the printing of maps showing the proposed location of reservoirs and dams, power companies have taken out permits for construction. The State, however, gives the Flood Commission notice of any hearing before a permit is granted and provision is incorporated in the permit that the foundations and construction of any

dam for power purposes shall be so designed that if, in the future, additional height, sufficient to control the flood peak be desired, the dam can be extended sufficiently high for that purpose.

The United States Government exercises control over all the regulatory bodies in the respective states. It grants no permit without the co-operation of the commonwealth in which such permit is desired. This is an insurance against any grant being so framed that it would in any way be a menace to navigation.

River Terminals. The amount of freight handled on the Allegheny, Monongahela, and Ohio Rivers in the Pittsburgh district for 1920, the date of the latest official report, was:

Rivers	Tons
Allegheny	4,948,276
Monongahela	25,264,354
Ohio	4,733,620

A large part of this was from one terminal to another but owned and operated by private enterprise.

Coal in quantities passes up and down our rivers but most of it is mined, transported, and consumed by private corporations. It is private because there are no facilities for the public. Why did not the corporations owning the mines ship to their mills by rail?

Some years ago, Senator Burton was holding a public meeting concerned with navigation, in Washington, by request of certain shippers on the Monongahela River. He turned to one at that time the biggest shipper of coal down the Monongahela River, and asked him if his mines were in the Pittsburgh district, and of course, his reply was "Yes". The Senator then said: "Well, sir, what is your freight rate from your mines to your furnace and rolling-mills by rail?" and the answer was "42 cents." "What does it cost you," the Senator then asked, "to transport your coal from your mine tipples by your own boats to your own furnaces and mills?" and the reply was "from 4½ to 7 cents a ton." That dialogue shows why our big mill owners own their own steamers, their own barges, and boats for their own transportation of coal. These great mill owners do that in order to stay in the market.

It is very questionable if the steam railroads could handle this additional tonnage of coal and insure anything like the prompt delivery possible by water. If private enterprise has profited to such an extent by using our rivers, why not let the public enjoy some of the advantages and profits of river transportation?

Traffic Relations between Rail and River Transportation. The remark is commonly made by those interested in navigation that the steam railroads will not enter into any traffic relations with water transportation. Would any sane man expect them to when the river transportation or would-be navigators have opposed in our city every effort made to establish a terminal? No railroad is going to trifle, or enter into any traffic relations relative to river transportation, until there are facilities to receive and dispatch freight, handle it after receipt, and deliver it with some assurance of promptness and safety. A bill of lading from a railroad is both a receipt and an assurance of safe delivery.

In river transportation to-day what guarantee is there against loss; what guarantee to-day against damage due to exposure; what insurance is there against theft of parts of machinery dumped on our cobble-stone wharf? The answer may come back from the navigator that there are wharf boats. Such an answer is in keeping with his sense of intelligent progress. If there is to be, at any time, a transfer of freight between the railroads and the water terminals, it should not be attempted along the river front in the central business district, but should be at the respective terminals of the main trunk-line railroads. For instance, somewhere at or near McKees Rocks a terminal arrangement can be had with the Pittsburgh and Lake Erie Railroad; at Glenwood, with the Baltimore and Ohio Railroad; and at Sharpsburg with the proposed new terminal of the Pennsylvania System.

Furthermore, these can be made safe harbors. The stock argument of the river interests in their opposition to the proposed river improvements in the city bond issue of 1911 was, as they claimed, that the proposed wall along the Monongahela and Allegheny Rivers would destroy the harbor for navigable craft during time of floods. If that be true, then a very safe

harbor which would hold all the craft that will ever come into this section, could be made by closing the upper end of the back channel of Brunot's Island.

Traffic Relations between River Terminals and Truck Transportation. Assume that river terminals were built the same as all over Europe and that it were possible to handle freight to and from river boats with the same power and facilities with which the steam railroads are now equipped, and that the steam railroads refused to enter into any traffic relations. That should only act as a stimulant, for the time has come in the designing of river terminals when all goods can be received and dispatched by trains composed of trucks that will radiate in every direction and go everywhere, go where the railroads would never think of going and in a fraction of the time it would take to have the same goods shipped by rail to the nearest railroad station. There is no reason why freight received at Pittsburgh by boat should not be delivered by trucks the same day even to a distance of a hundred miles away.

Solution of Problem by Wharf Construction. How can this be accomplished? How can the cost of living be materially reduced? How can produce and merchandise required in our local markets, be delivered from down-river points with greater facility and less cost, thereby greatly reducing the cost of living, and providing a great impetus to packet, produce, and light freight transportation, leaving for the steam roads the heavy tonnage and the through hauls? The answer is, *build a modern wharf.*

What can be done to interest our city, interest the public who will receive the direct benefit of such an improvement, to the extent that they will vote for a city bond issue to meet the expense of the improvement that will come from the building of a modern wharf—an improvement that will reclaim at least 40 acres between the building line along Water Street and Duquesne Way and the river face of a wall extending from the Smithfield Street bridge to the Point, and up the Allegheny River to Ninth Street.

Such an improvement will:

1. Correlate with the major street plan for Pittsburgh.

2. Constitute one more unit added to the completion of the outlet for the Lincoln and William Penn highways through Pittsburgh and on westward.
3. Correlate with the city's sewage and drainage systems.
4. Afford a protection against floods, by elevating low places in Water Street and Duquesne Way.

The reclaimed wharf will provide for modern river terminals and warehouses, an 80-foot boulevard, and parking space for 5000 automobiles.

The building of the walls, the filling back of them, the construction of the boulevard and warehouses can all be done at a cost of about $2,500,000, based on present prices.

Wharf Encumbrances. There are few obstacles other than changes of grade along the wharf on the Monongahela River. Along the Allegheny River it is quite different. Immediately on turning the Point, the whole of the river front is cut off by the Exposition Building, which, if a wharf is constructed along the Allegheny River, should be entirely removed. The next, and most serious, obstacle to the improvement of the wharf is the tracks of the Pennsylvania elevated road passing down the Allegheny wharf to the Point. If these tracks are allowed to remain on the wharf, they should be moved out to the pool-full line or to where the face of the proposed wharf should be placed.

The approaches to all the bridges would have to be changed. The grade of Duquesne Way should be raised at least to high water. Should the wharf be extended to Eleventh Street the passage under the Pennsylvania Railroad would have to be reconstructed. If Pittsburgh could enter into a deal with the Pennsylvania Railroad that would call for the removal of tracks along the left bank of the Allegheny River, from near Eleventh Street to the freight yards at the Point, both would be gainers. There would be no occasion for additional crowding and congestion in the central business district of the city for many years to come.

The city council should be very careful in signing up any wharf privileges that might interfere with future wharf improvement.

The Pennsylvania now owns and controls 20 acres at the Point. Sixty acres can be reclaimed by the building of a wharf, thereby adding about 20 acres, net, of building area, 20 acres of improved streets and boulevards, and about 40 acres devoted to navigation. All of this 80 acres added to the area of the central business district would be an addition of 40 per cent.; or nearly 30 per cent. exclusive of the 20 acres of the Pennsylvania Railroad. If there were to be no improvement in navigation, the merits of the proposed improvements in the relief of congestion and the added speed of vehicular traffic would justify a bond issue covering all the proposed expenditures.

The engineers of Pittsburgh and vicinity can perform no greater act of loyalty and co-operation in the maintenance of Pittsburgh's perpetual supremacy, than that of championing wharf improvement.

That New Orleans has benefited much from the splendid results in wharf improvements and water terminals, is due to the fact that four public-spirited business men of ability are appointed by the Governor of Louisiana to look after the wharves and shipping interests of New Orleans.

Pittsburgh should have a like representative body to see to it that we enjoy all the benefits that can come through adequate wharf improvements and transportation facilities. Transportation on our rivers is free. The use of our locks is free. They should be used freely, and a commission for Pittsburgh, like the one in New Orleans, will stimulate trade on our rivers.

When Archbishop John Ireland was a guest of Pittsburgh on Columbus Day, in 1909, he was taken over the Point bridge and requested that he be permitted to alight from the automobile. Doffing his hat, he said: "I salute you, La Belle of History, the Great Ohio River, this wonderful stream that has made so much history for this great country," and turning around, extending both his hands to the Monongahela and Allegheny Rivers, he used these words: "Do you Pittsburghers know how kind God Almighty was to you and how much he has done for this wonderful City, with its three great rivers, its many valleys and hills, dotted with fuel for years to come? If you are not filled with

civic pride, you certainly show a lack of appreciation for your wonderful City. Pittsburgh is known all over this broad land, and in every country, and without your wonderful progress in steel, our great Northwest could not have become the great country it is."

DISCUSSION

Major J. F. Bell:* This excellent paper by Mr. Morse has been delivered at an opportune time on a subject which is of urgent importance. Shipments by river to and from the Pittsburgh district are growing in number and magnitude. Applications for private use of part of the waterfront in the business section are now before the city authorities. If Pittsburgh does not direct the growth of her waterfront, it will grow up in a haphazard way and have to be rearranged and rebuilt a few years from now at great cost. We must have properly constituted authorities created and a general plan adopted at once. Very little money need be spent now. Under intelligent and businesslike management, the whole proposition can be made a paying proposition—something that will be an asset to the city and not a drain on the public purse. In addition, we shall have increased property values and better traffic facilities.

We must study what has been and is being done at other points—at New Orleans, St. Louis, Nashville, San Francisco, Seattle, and New York—and learn from the mistakes that have been made. The greatest mistake has been delay; the next greatest has been poor management.

The following is quoted from a report on Water Terminal and Transfer Facilities published in House Document 109, 67th Congress, First Session.

"189. Our review of the port situation of the United States shows:

1. That there is not in most of them a well co-ordinated management, and that well constituted port authority is the first need.
2. That under these port authorities comprehensive plans based on principles hereinbefore laid down should be evolved.
3. That a port can only be successful when this plan is based upon the business available in its tributary area, and brings ample railway facilities into the closest practicable juxtaposition with the water front, with sufficiently wide areas available for cargo classification.
4. That with the increased cost of labor, mechanical means should be adopted, wherever practicable, for handling goods, and that such means should be at hand for every kind and shape of package.
5. That ample railroad tracks should be available close to the terminal for car storage and car classification.

*U. S. Engineer Office, Pittsburgh.

6. That ample warehouse capacity should be provided, in order that both ships and cars may be dispatched in the shortest practicable time. Too many of our ports are lacking in warehouse facilities, or have such facilities at inordinate distance from the terminal, thus involving cartage or extra handling for local railroad haul.

7. Where cartage is necessarily a feature in the port business roadways and loading platforms should be provided for the full accommodation of trucks.

8. That bunkering facilities of such character as to supply the necessary fuel to the ship while handling cargo should be available.

9. That ample repair and dry docking facilities should be provided.

190. No matter how ample the provision of terminal piers, sheds, railways, and mechanical equipment, a port will only succeed under an efficient and well coordinated management."

These fundamental facts have been determined after thorough investigation. It is our problem to apply them to our particular needs and then act.

MR. WINTERS HAYDOCK:* A consideration of river-front improvements will to a certain extent assume the nature of a review of features which are more or less familiar to all engineers and others who have given much thought to civic affairs and which have in some cases been the subject of official reports. For example, the 1917 report of the Transit Commissioner, Mr. Morse, goes into the matter of river-front thoroughfares for the triangle district.

In discussing the relationship of river-front improvements to the major street plan of Pittsburgh, I will assume as a basis for discussion the adoption of a major street plan similar to that proposed by the Citizens Committee on City Plan of Pittsburgh. This is a scheme which defines the city's main routes of circulation as they should be developed in the future and suggests for each portion an appropriate traffic capacity. It includes among other features a system of inner and outer by-pass thoroughfares designed to permit all traffic not having business in the triangle district to avoid passing through the interior portion of that district. An analysis of traffic made by the Citizens Committee in 1920 revealed the fact that over 18 per cent. of the traffic entering the central business district was through traffic

*Chief Engineer, Citizens Committee on City Plan of Pittsburgh, Pittsburgh.

which was compelled to pass through this most congested part of the city because of the lack of a system of by-pass thoroughfares. As a considerable proportion of this through movement consists of heavy slow-moving traffic, the importance of its elimination is too obvious for discussion.

Essential elements in such a by-pass system are adequate thoroughfares located upon the periphery of the congested district which it is sought to relieve. Streets of ample traffic capacity must therefore be provided along the river-front boundaries of the business district. The provisions for by-passing to the east of the triangle, and the exterior by-pass system included as a part of the major street plan proposed by the Citizens Committee, are related to the river-front problem in so far as they affect connections with these two river-front streets. But there is another function which properly developed river-front streets will perform which is of equal importance with their function as by-pass arteries. They would become important distribution or header streets for traffic of which the destination is within the triangle.

To serve this double purpose properly these water-front streets and their connections should be developed along the following lines.

On the Allegheny River front there should be a street having a roadway of width sufficient for not less than six lines of vehicles; that is, having a roadway about 54 feet wide, with ample sidewalk space in addition. This street should extend from the intersection of the Point bridge and the Manchester bridge approaches at least to Tenth Street, and preferably beyond. From the standpoint of plan, this water-front street should connect with Eleventh Street as that street will become a direct continuation of Grant Street when the proposed relocation of the latter north of Seventh Avenue is put into effect. Thus if Eleventh Street and Grant Street were widened to 80 feet we would have a continuous six-line thoroughfare between streets near the Allegheny and Monongahela river fronts. However, we should not lose sight of certain difficulties in the way of this theoretically preferable plan. For example it would be

necessary to reconstruct the crossing under the tracks leading to the Pennsylvania Railroad bridge; and there would also be an interference with one bay of a building of the plant of the Mackintosh-Hemphill Company.

This plan contemplates the raising of the grade of Duquesne Way at its western end to meet the intersection of the approaches to the Point bridge and the Manchester bridge. The resulting gradient between this intersection and the first street to the east, Barbeau Street, would be moderate. The removal of the old Exposition buildings, a future probability, would make possible the proper width for this portion of the thoroughfare.

The securing of a proper width for this street east of the Exposition buildings is dependent upon the ability of the city to extend the width of level ground beyond the north street line of Duquesne Way. The building of the suggested quay wall would make this improvement possible.

A serious, though not insurmountable obstacle to the proper development of a thoroughfare on the Allegheny River front exists in the elevated structure of the Pennsylvania Railroad. There would appear to be three possibilities to be considered in connection with this phase of the problem:

1. A solution of the terminal requirements of the railroads and the shippers which would permit of the removal of this structure from the river front.
2. The conversion of Duquesne Way into a one-way, east-bound thoroughfare, and the building of a balancing west-bound thoroughfare on the river side of the elevated structure.
3. The shifting of the elevated structure toward the river far enough to permit of the widening of Duquesne Way to the required width.

There can be no doubt but that the first of these three schemes would be the ideal solution from several points of view. But unless some authoritative plan for the removal of this structure is worked out we will probably have to assume that it is to remain.

The next most desirable solution is without doubt the third of the foregoing schemes. A wide double-sided street would be better than two narrow one-way streets with an ugly steel viaduct in the middle. An examination of the route of this viaduct will show that its alignment would be improved by the suggested shifting. Furthermore, we should not lose sight of the fact that this plan would make available the space beneath the viaduct for commercial or other purposes.

Before leaving the question of the Allegheny River front I will call attention to the relationship of the three Allegheny bridges to this river-front thoroughfare, and I will quote the following paragraph from the major street plan report of the Citizens Committee on City Plan.

"It is possible that in the future it will become necessary to rebuild the three bridges over the Allegheny River located at Federal Street, Seventh and Ninth Street. If the Allegheny and Monongahela River fronts are ultimately to be improved with vertical quay walls, these walls, in order to give a maximum return on the investment involved, should be placed as far out from the present shore lines as the Government will allow. It is therefore obvious that in designing the new Allegheny River bridges, consideration should be given to this possibility, and that, in so far as possible, the ultimate location of river front structures on both the south and north banks of the river should be ascertained before these bridges are rebuilt."

Turning now to the Monongahela side of the triangle, we should widen Water Street from the Point to Ross Street to a width sufficient for not less than six lines of vehicles. This again would call for an extension of the flat ground toward the river. The suggested quay wall would make it possible.

The principal problem to be solved on the Monongahela side would be the planning for an approach from Water Street to the proposed bridge to be built across the Monongahela River to the Liberty Tunnel. As a matter of plan it would seem to be much better that the greater part of the very heavy traffic which will some day use this bridge be delivered to a properly widened Water Street as a distributing street rather than to the already congested eastern entrances to the triangle. It should certainly not be added to the load to be carried by the new Boulevard of the Allies.

Such an approach would be made possible through a re-arrangement of the Baltimore & Ohio Railroad passenger terminal facilities and the co-operation of the Federal government in the matter of shifting harbor lines. The building of a new and finer depot by the Baltimore & Ohio Railroad is something to which we may confidently look forward. The fact that the city owns the river-front property between Grant Street and Smithfield Street which is now occupied by the Baltimore & Ohio passenger depot has a bearing on this case. The most advantageous arrangement would probably call for the removal of all freight facilities from the western side of the "Panhandle" railroad bridge and the building of the new passenger train-shed to the east of Grant Street projected.

This westerly bridge approach could pass over the "Panhandle" railroad bridge near the first river pier, and, with a proper adjustment of the harbor line, continue along the new river edge to a connection with Water Street. The location of this connection would depend in part upon the use to which the reclaimed area on the river front is to be put. The main approach could pass under the Smithfield Street bridge, thereby helping to relieve congestion at the end of that bridge. Another connection could be made by extending Grant Street south from Water Street to meet this approach. This would require a raising of the grade at the intersection of Grant and Water Streets, which however would not be a serious matter. This extension of Grant Street might even pass through the structure of the new passenger depot with pleasing architectural effects. The maximum grade on the suggested approach would be five per cent.

The foregoing is a sketch of some of the improvements in our thoroughfare system which a proper development of the river fronts will make possible. It is hard to see how we can hope for a satisfactory solution of our growing traffic problems unless some improvements having similar results are to be put into effect.

MR. FREDERICK BIGGER:* Discussions of such an important phase of the planning of Pittsburgh as that having to do with the down-town river front and wharf development must necessarily bring out the specific points of view of the engineer, the transportation expert, the manufacturer, the business man and others. It may be of some interest to indicate the approach of the town planner to the subject, inasmuch as this approach is primarily concerned with the general problem of relationships and secondarily concerned with problems of detailed design and construction in so far as these affect such relationship.

The factors or elements involved in the general problem might be very simply enumerated or listed. I believe it is better to submit a brief descriptive outline indicating their correlation. This may appear purely theoretical because some of us believe that, in practice, there will probably be deviations and compromises due to:

1. Lack of basic facts and information.
2. Inadequate or inaccurate analysis of those facts which are available.
3. Lack of broad vision and foresight.
4. Special, selfish, or partisan interest.
5. Apathy and inertia on the part of those who should be interested.

RELATION TO STREETS AND TRAFFIC

This phase of the problem involves the study of the waterfront streets as they are at present in location, capacity and arrangement, or as they may be shifted or modified in position, enlarged in capacity or revised in arrangement—all this with respect to their use by traffic of different character, as follows:

1. Through traffic of all kinds desiring to by-pass the business district.
2. Local traffic, chiefly trucking, which originates or has its destination, or both, in establishments not on wharf property and not pertaining to wharf usage.

*Architect and Town Planner, Citizens Committee on City Plan of Pittsburgh.

3. Traffic, both commercial and pleasure, which has its origin or destination upon the so-called wharf land, whether or not such land be developed for strictly wharf use.

In connection with the foregoing, there is the problem of the bridges, considered:

1. As parts of the street plan directly contiguous to, and integrated with, the water-front streets.
2. As physical structures which intersect, either at grade, overhead or underneath, the strip of river-front land, or structures to be built thereon.

RELATION TO TRANSIT FACILITIES

In this phase of the subject one is compelled to recognize the fact that many proposals, official and unofficial, have been made as to the disposition and arrangement of street-railway facilities in the business district. No matter how immediately practical any suggestion may appear which is specific with respect to the use of the surface or sub-surface of any streets in the business district, I think we must admit that the facilities in this district must be a part of a co-ordinated transit system for the whole city. There is therefore implied the making of a "transit plan" such as that now being studied by the Citizens Committee on City Plan. A comprehensive plan of this kind should answer the following questions with respect to adjustment of street railway facilities to water-front streets and wharf land:

1. Will surface cars occupy the water-front streets?
2. Will elevated or subway lines be located here?
3. Will a rapid-transit loop be desirable on any part of the wharf land?
4. Will a proper use of the wharf demand the extension of street-cars tracks upon wharf land, either to meet street-railway needs or to integrate transit lines with river terminals?
5. Will electric-railway terminals of any kind be located upon the wharf?

6. Will a proper wharf development scheme require adjustment to the crossing of this territory, or encroachment upon it, by any surface, elevated or subway lines leading into or out of the business district?

RELATION TO RAIL AND WATER TRANSPORTATION AND TERMINALS

These phases of the problem are not to be separated even in an outline. The problems involved probably bulk larger in the minds of those present than any other aspect of the general problem. Study of these phases involves the development of schemes adjusted to existing needs and to future growth with respect to location and character of boat landings and moorings, location of trackage, facilities from transfer of freight by approved and economical methods of various kinds between railroad cars and boats or barges, and between each of these and trucks and warehouses. It involves a study of the needs of the shippers and importers. It requires adjustment to the legitimate needs of either rail or water transportation companies for individual facilities, with due allowance for expansion. It involves consideration of the problem of public ownership or operation, or both, of terminal facilities. Throughout this phase of the study it should not be forgotten that the Water Street and Duquesne may be developed and that, for any given facility or structure, Way locations are not the only parts of the river-front which the value and desirability of development of other sites must also be considered.

FLOOD PREVENTION AND FLOOD PROTECTION

This aspect involves those problems already so carefully studied by the Flood Commission. It implies decision with respect to measures of flood prevention and control beyond the City of Pittsburgh. Similarly, it implies decision with respect to the hydraulic cross-section of the rivers, the height and type of quay wall or walls which may appear adequate in meeting all needs.

SEWERAGE AND DRAINAGE

Briefly, the study of this phase involves such planning and adjustment as will:

1. Provide for the proper ejection of sewage from the mains in the business district into the river, so that present conditions in this respect are maintained or improved and provision made for future development of a sewage disposal system. This naturally includes provision for sewerage of the developed wharf land and buildings, and in any case the backing-up of sewage should be eliminated.
2. Provide for the drainage of areas now drained, as well as of the rearranged or remodeled wharf land, and buildings which may be built. This provision should include protection against seepage in times of normal river flow as well as during floods.

PROBLEMS OF LAW AND REGULATION

This aspect is of special importance. Original grants of wharf land, in some cases, perpetually preclude the use of such land for any other than wharf purposes. Given comprehensive plans, thoroughly devised as to physical arrangement and human use, there may well arise the desire to modify or reinterpret the law so as to permit progress along modern lines of wharf development. In the meantime, governmental laws and regulations imposed or enforced by the War Department, which thus controls the rivers, may appear desirable of modification. For example, there is involved the question of location of the harbor lines and any changes therein which may be suggested. This, in turn, involves the development of such a general scheme or schemes for the use of the definitely circumscribed land and water areas that the fullest use of each may be secured without interference of the one with the other.

RECREATION AND THE SOCIAL ASPECT

There are two phases of the social aspect of the general problem. One phase has to do with the assurance of convenience and

safety to all persons who may make use of the commercial facilities which are developed. This is naturally implied throughout the present outline and further mention of it is unnecessary.

The second phase involves the study of special recreation facilities. Such study should produce answers to the following questions:

1. How much of the wharf property shall be given over to specific social use for recreation?
2. Which portions of the area may be so developed without undue interference with commercial development?
3. What types of recreation development should be made?

THE ESTHETIC ELEMENT

Extended argument in favor of beautification is not permissible here. Any development which may be made can be judged as to its artistic merit. Good, bad, or indifferent, some verdict is inescapable; therefore, I believe the artistic element must be recognized as essential. It is essential in any park development and equally essential in the development of the commercial elements. Whether we are concerned with a building, a bridge, an open space, a street, or a city, the beauty of the fundamental structure (which is the only true beauty) is to be secured only through the exercise of both *artistic* designing ability and *structural* designing ability by those who arrange the structural elements. Granting that the utilitarian problem must be adequately solved, it must be remembered that the mere application of ornament or color, no matter how profusely used, cannot conceal the inferiority of a structure which is poor in its fundamental artistic design.

SUMMARY

City planning appears to me to mean the consideration and decision of questions concerning the character and relation, one to the other, of various parts of the city; various elements of its physical make-up; and various aspects of the life and activities of its citizens. It is a complex field in which are involved factors which are physical, social, and economic. It cannot be

approached safely by methods of snap judgment. The future must be considered. Ultimate practicality may mean more than immediate practicality. It is a fatal policy which says "let us get something done, no matter what it is." Any scheme or plan will be good or bad, therefore, in proportion to the thoroughness with which the planners have analyzed and correlated the various elements in the problem and none of the problems mentioned in this outline should be considered alone. As each is studied there must be a constant study of its relationship to all the other problems of the comprehensive scheme. Only thus can we avoid over-emphasis in some places and under-emphasis in others.

If this subject of water-front development is considered comprehensively, we can hope for an ultimate improvement which will be enormous in value, striking in appearance, wide-spread in its influence, and a development of which Pittsburgh will be justly proud.

PARK DEVELOPMENT AND BEAUTIFICATION

In the preceding outline were included items pertaining to recreation and to beautification. It was taken for granted that these items required no justification.

None but the most phlegmatic and unimaginative citizen will dispute the contention that provisions of recreational character are vitally important and should be included in any comprehensive plans of the down-town waterfront. At present the men and women workers of the business district, after lunching or dining, may spend the few remaining recreation minutes free to them in the dairy lunch room, the William Penn Hotel cafeteria or the Duquesne Club, or in walking or loitering on the crowded sidewalks. With properly located and designed waterfront parks there would be opportunity for re-creating energy, interest and enthusiasm and opportunity for refreshing the body and the mind. Workers so refreshed represent increased economic efficiency; but, even if this were not true, I hold that the social gain in enabling people to improve in health and alertness, to become less like machines and more like

human beings, is in itself complete justification for making the proper development of open spaces for the purpose.

Normally, perhaps, what we call the strictly utilitarian needs of commerce must be given precedence. These will not entail the utilization of every bit of land. After legitimate utilitarian needs have been met, there will be a residue of land which can safely, and without opposition, be developed as a park or parks. It may even be worth while to make concessions from the commercial development in order to secure a more useful park development. I say this with full realization that it may appear like business heresy, but with an equal realization that the general object is to achieve a well balanced development in which no vital part is unduly restricted in an effort to overemphasize some other vital part. I hold the recreational use a vital one; man cannot live by bread alone.

Because this need is so vital, I personally do not approve of any scheme which sets a precedent for, or implies the permanent use of, any public space on the waterfront for the storage or parking of the inanimate and privately owned automobile. Direct human needs are greater; the majority of the workers in the business district do not own automobiles, and I would give their recreation needs first attention. I would meet the disturbing problem of automobile storage by the erection, in suitable locations, of properly designed storage garages. These might preferably be privately owned and controlled, but in any case the automobile owners as a group are the legitimate payers of the bill.

I can see no argument for the inclusion of playground equipment or facilities, and no convincing argument for any athletic facilities, in the areas under discussion. The need is rather for a park, or parks, laid out with walks, planted with trees, shrubs and flowers, equipped with many conveniently placed seats, and having any additional architectural or sculptural elements which may be desired for the purpose of adding to the attractiveness of a "rest" park.

Before basic information on the various phases of waterfront development has been secured, analyzed and correlated, *definite*

suggestions as to extent and type of park development should be made. However, one may freely make a number of rather loose and general suggestions to which some study may later be directed.

The Point. A more or less formal park development should be made at the actual Point. The minimum area which should be studied as a scheme unit is that bounded by the north and west lines of the Pennsylvania Railroad's Duquesne station property and the rivers (or river walls, if any) from Penn Avenue around to Barbeau Street. The scheme should eliminate the Exposition buildings. It should include adequate roadway approaches to the bridges on Water Street and Duquesne Way, a carefully studied arrangement for the traffic intersection of these roadways and those on the bridges, decision as to the exact location of the end of the proposed new Point bridge, raising of the actual point of land between the bridges to the level of the adjacent approaches and the creation of a "look-out" space thereon. This raising of the land might extend eastward over the unbuilt-upon ground west of the Exposition music hall and from there be terraced down to the general wharf level established by the quay wall. The park area thus made should be designed with parterres of lawn, flowers and shrubs; trees should be planted, walks and balustrades constructed, benches placed, and possibly a sculptured memorial incorporated into the design. In the latter event the greatest possible care should be exercised in determining the "scale" of this sculpture because the whole tract will be dominated by the huge bridge structures. A slight stretch of the imagination might enable us to visualize the moving of the Block House to a specially prepared setting as a part of this scheme. Such a proposal would no doubt be opposed by the patriotic ladies who control that historic structure, but there would appear to be at least one important precedent for such action in the removal of the little brick house of William Penn from down-town Philadelphia to its present much visited location in Fairmount Park.

Parks at Bridge Ends. Developments of somewhat similar character might be made at the ends of the Smithfield, Sixth,

Seventh and Ninth Street bridges. Here is good opportunity for more or less formally arranged park treatment. Adequate provision for traffic must be made, but additional space might be set aside for development in parterres of planting, walks, seats and drinking fountains. If this were done we should escape the present feeling of being almost forcibly propelled from the bridge, across Duquesne Way or Water Street, into the canyon of street ahead of us. Instead we should have a feeling of freedom, opportunity to pause at the river's edge to enjoy the beautified open space and the perennial interest of the river itself. My own feeling is that some of these parks might be extended, perhaps merged with an adjacent one; and that the same idea might be developed opposite the ends of Wood, Ferry, and Stanwix Streets. Retention of the elevated structure on Duquesne Way will make the designing of the park features more difficult than if this structure were removed, but I see nothing impossible in the problem provided the designer were free either to mask or embellish the viaduct structure wherever adjacent to the park development. Personally I should prefer to see the viaduct removed, but would await with an open mind convincing proof that its retention is necessary.

Special Development of Water Street. It appears to me that a special development similar to that just mentioned might be made upon the Monongahela River front, extending from the Baltimore and Ohio Railroad passenger terminal westward to Wood Street and perhaps even farther. It appears probable that a new terminal, when it is built, will be withdrawn eastward so as to leave vacant that city-owned property upon which the present station building now stands. There is a great opportunity here for the architect to design a particularly handsome building in a particularly interesting setting. A phase of the designing would include the creation of some architectural feature symmetrically placed on the axis of Grant Street so that the interest of this street would culminate in the station building. The west façade of the terminal, if properly designed, will suggest the idea that this is an entrance to the city, that visitors arriving here will emerge from the station portals into the city.

It is therefore important that they do not get the idea that it is a neglected rear entrance, but rather a main entrance of dignity and beauty. To secure this effect I would develop park features the lines of which in plan would be more or less formal and be integrated with the architectural features of the façade. Therefore, between the widened roadway of Water Street and the quay wall (or the wall separating the wharf level from the ramp which may descend from the Liberty bridge), there should be developed a scheme of walks, parterres of lawn, grouping of shrubbery, a rather profuse planting of trees, space for many benches so placed as to afford a view of the river, and any special features such as drinking fountains, statues, balustrades and the like. Cross walks would be necessary, parallel to and at each side of the Smithfield Street roadway. Similar cross walks would be provided opposite the end of Wood Street and, if the park extended so far, also opposite the end of Market Street. I would block entrance to the park between these streets so that pedestrians would cross Water Street only at street intersections. From the park level, which presumably would be that of Water Street, steps or ramps would descend to the water's edge or to a walk at a lower level near the water. These would be adjusted to afford access to water craft, and it would therefore be necessary to adjust the capacity of such facilities as well as the width of cross walks so as to handle passengers from excursion boats without entailing damage to trees or planting because of the inadequacy of these provisions. At a proper location, probably immediately west of Wood Street, I would erect a well-designed open pavilion or band stand constructed of the same material as the railroad station, located on the longitudinal axis of that building and of the park. If this band pavilion were located on the axis of Wood Street it would be a local point adding interest for those who approach the river on that street.

The Citizens Committee on City Plan in its Report upon a Major Street Plan for Pittsburgh gave its opinion that "the down town water-front should be an open development chiefly arranged as a public park with necessary adjustment for essential wharf uses." I think the fair implication is that actual

terminal buildings may after proper study, be found to be more advantageously placed elsewhere. This Committee is now making a recreation study of which the down-town waterfront will be a part. The Committee is leaving this problem until the last, until more information as to utilitarian needs has been secured. Therefore, what I have suggested here is merely personal generalization. However, I think we should keep in mind the necessity for recreational development and for fundamental artistic treatment along the river front, both for the satisfaction of our citizens and for the appeal that will be made to visitors. Visitors will carry away an indelible impression, either of neglect, as at present, or of alertness and civic pride if the problem is properly solved.

MR. A. H. BURCHFIELD:* I am not an engineer and I suppose what I say may be punctured full of holes. I think there is crying need for a number of things in Pittsburgh. First, we need to provide proper protection against floods. There certainly is no good reason why Pittsburgh should have to suffer again as it did from the great flood of March 15, 1907, causing millions of dollars worth of damage. The damage was not all caused by the water from the head-waters of the Allegheny and Monongahela Rivers overflowing the banks in Pittsburgh, but was caused largely by heavy local rains and lack of a proper sewerage system and means of preventing sewage from entering the basements of the buildings. Second, there is the transportation question. Having been in business in down-town Pittsburgh for 36 years, I believe I know something about the transportation question. I have studied it because I have to use it and, naturally, I am vitally interested in it.

Of course there are other problems to solve in the triangle known as the "down-town district" in addition to floods, sewage and transportation. We also have the parking and street widening problems to solve. Studies are being made to correct all of these and in so doing it is hoped that a number of them can be corrected at the same time.

*Vice-President, Joseph Horne Co., Pittsburgh.

My solution in part would be a subway from the East End, which would come out at grade and be elevated past the Pennsylvania station, north on Tenth Street, west along the Allegheny River on an elevated structure, around the Point, up the Monongahela River past the Baltimore & Ohio station turning to the right into a subway. By this arrangement, every car that comes into the down-town part of the city could use the loop and make a complete circuit. This loop, or belt line, could be connected up with the West End, South Side, and North Side cars by one of several methods.

Needless to say, the triangle is a congested area and we have spent a lot of money to correct some of the congestion and will be obliged to spend a great deal more in the near future. It is said that almost one-third of the down-town triangle is not used to advantage and cannot and will not be until adequate transportation facilitates are provided. I see no reason why cars could not be looped by this method and practically every spot in the triangle served and become good business property. If this loop were built around the city and 15 loading stations put in, the load or crowd at the station wanting to get on would be divided into 15 parts. Then these 15 stations could be divided into five or six platforms. There about 120 cars per hour (on an average) either coming in or going out of the city at the peak time. With a six-track elevated line, these cars would loop the city much faster than they are now doing on the surface and this arrangement would allow the streets to be used principally for automobiles, trucks and other vehicles, as well as pedestrians. It is very evident that our streets are inadequate for the use to which they are put and something must be done to relieve the congestion. In other words, somebody must get off the streets in the down-town triangle. If the street cars are kept to the wharves, or the rim, it will help solve the problem and provide proper facilities for taking care of the one-third of the triangle which is not now used to advantage and which can be made as valuable as any spot in the city.

We should also have wharf walls built at the earliest possible moment. They should start at the Point and extend up river on

the south bank of the Allegheny and the north bank of the Monongahela as far as possible at this time and later take in such other portions of the river banks as found necessary and practicable.

If wharf walls and an elevated loop for street-cars are built, at the same time recreation and parking facilities could be provided and proper provision made for river transportation at comparatively slight additional cost, and a system installed for better taking care of the sewage of the city during flood times, so as not to cause much damage to the basements of the down-town business properties.

There are still a number of streets in the down-town section which should be widened, such as Water Street, Duquesne Way, Stanwix Street and several others. All of these improvements should be considered at one and the same time, as it goes without saying that if the river wall, elevated loop, subway, street widening, and sewage system improvements are undertaken at the same time, the cost will be considerably less.

I hear someone saying, however, "Will the traction company help pay for it?" It seems to me that that is immaterial. Even if the City of Pittsburgh makes certain of these improvements and hands them over to the traction company on some equitable basis, in time they would certainly pay for themselves from increased taxation and increased prestige and business which would be bound to follow from the more efficient use that would be made of all the down-town property, as there is still considerable property that is paying comparatively little taxes and causing a great deal of dissatisfaction. Once this property is provided with adequate transportation facilities, etc., it will undoubtedly increase in value and should be worth from 6 to 10 times more per foot front.

If the transportation system suggested were now in operation, we could leave this hall, walk possibly half a square and select one of six platforms, from which we would take the car that would transport us to our homes, instead of walking to the terminal of the particular line that we use. In addition,

there should be certain cars that would bisect the city, passing under this loop and giving transfers.

MR. E. LOGAN HILL:* Cheap water transportation has always existed but its importance has never been fully recognized. It has been said that there is no large city in the world that is not located upon a navigable waterway, and I remember some years ago hearing it said that Worcester, Mass., was the largest city in the world not so situated. The population in Worcester at that time, if my memory is correct, was about 160,000.

Cheap water transportation is, of course, most desirable from an economic point of view, providing proper advantage can be taken thereof; and by this I mean the cost of loading commodities on and removing them from the river steamers or ocean-going vessels, as the case may be. For example, a ton of billets might be conveyed by water from Pittsburgh to Cincinnati at a rate one-half of that charged by rail transportation, but it is obvious that if it cost equally as much to load the billets on the boat as to move them down the river, then the water rate has no final advantage over the railroad. It would follow that in order to take advantage of cheap water transportation economical means for loading and unloading commodities must be provided. This proposition is, of course, equally true of railroad transportation. In New York, for example, it costs more to load a crate of manufactured articles in a box car than it does to transport this crate half way to Chicago, after it is in the car.

One does not pursue this process of reasoning long, before he concludes that the problem of handling freight mechanically so as to reduce the cost is a pressing one, and one which is well worthy of proper solution.

The subject of handling freight by mechanical means can be divided as between bulk material in the first case and package freight in the second case. The latter division is in itself divis-

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ible into two parts, namely, heavy package freight and miscellaneous package freight. In different parts of the world these problems have been worked out with varying degrees of efficiency, but there is no other place where the handling of bulk cargoes has been developed to such high efficiency as in this country.

I refer specifically to the methods of handling ore and coal at the ports on the Great Lakes. The development of this art has been carried to a high point of perfection by the genius of American engineers and designers, and it is but reasonable to conclude that equally satisfactory progress can be made in this country along the line of handling package freight.

I have often been asked why it is that in the port of New York, for instance, there are so few cargo-handling cranes, whereas in the great European ports there are hundreds of these efficient machines. This question seems all the more paradoxical when it is remembered that we unload in New York the commodities which are loaded in Europe and that we load in New York into the same ship material which must be unloaded in Europe. There is, therefore, no truth in the oft-repeated statement that the conditions differ enough to explain the absence of cranes in this country. The real explanation of the absence of more cranes on this side of the Atlantic lies in the fact that the steamship companies, before the advent of the longshoremen's unions, were in the habit of employing the crew on this side to unload the vessel using ship's tackle. It was thus possible to get along without cranes. On the return of the vessel to its home port in Europe, however, the crew wanted to go to their homes, and the necessity for cranes for unloading the ships in these premises was evident.

It has been five or six years since the first cargo-handling cranes were installed by Heyl & Patterson, Inc., of this city, in the port of New York, and it has taken a long time to convince the steamship and railroad companies and the municipal authorities of the soundness of the arguments that ships can be unloaded with less cost and with greater despatch by means of cranes than by means of ship's tackle. At the present time, however, this contention is more generally admitted and there

are now under construction a number of cranes being installed on one of the city piers.

This brings us to the subject of the type of crane which is best adapted to the work in question. To most people the word crane calls to mind a steam-locomotive crane. These machines cost somewhere between $15,000 and $20,000, and are very useful when properly employed. A locomotive crane regularly assigned to a particular locality and working through stipulated cycles of movement of travel, rotation, and hoist, is, however, not an efficient machine. In the premises just stated, electrical current nowadays being invariably available, much money can be saved by designing and installing electric cranes particularly suited to the work involved. Once this is done the steam-locomotive crane is immediately subject to these important disadvantages—time is lost in generating steam, procuring water and coal, and stand-by losses always encountered by steam-boilers are ever present. Further, locomotive cranes, involving as they do a multiplicity of clutches, brakes, gear levers, beveled gears, etc., are very expensive to maintain. The average maintenance expense on a 15-ton locomotive crane based on 11 such cranes on a division of one of the New York trunk-lines amounted to nearly $4000 a year.

If there are advantages, then, in the use of electric cranes, the next question to decide is what type of electric crane is best suited for the purpose in question. In general, there are two such types, one known as the straight-line crane and the other the revolving jib-crane. It is generally conceded that of the two the revolving jib-crane has the greater flexibility, whether or not the boom is of the luffing type. The reasons for this are as follows:

1. A straight-line crane working from a ship to the pier has a very small area in which to deposit its load on the pier. Unless these drafts are removed promptly the crane is delayed.

2. The revolving jib-crane on the other hand swings through an arc and there is, therefore, less liability of congestion at the landing point.

The capacity of a crane is the most important point to be considered. On any given pier such questions as these arise: Shall one 20-ton crane be purchased, or four 5-ton cranes, or ten 2-ton cranes; and here, again, the straight-line crane is subject to a disadvantage. The answer to these questions can usually be found by determining the average load to be handled in the case of miscellaneous package freight being taken from the steamer. The average load seldom exceeds 2000 pounds, so that a 2- or 2½-ton crane is generally considered to possess the most efficient capacity. Obviously, the occasional four- or five-ton load con be handled by two adjacent revolving jib-cranes by placing their booms together over the hatch as the load is hoisted from the hold. The booms can be rotated inward simultaneously and the cranes travel apart in such a way as to land this load at the proper point on the pier. Straight-line cranes as ordinarily built do not have their booms arranged to swivel in a horizontal plane, and, as a result, the booms cannot be brought together to handle the occasional heavy loads.

There are so many variables entering into the operation of handling freight (such as the weight and size of the package encountered, the type of ship or barge from which it is taken, the kind of freight-car on which it is to be loaded whether it is a box-car or an open car, the location of the tracks as referred to the point at which the freight is to be handled, the fixed structures or parts thereof that must be cleared by the freight in its path from the point of origin to point of delivery, etc.), that it is most desirable and well worth while to devote some study to these matters before making up one's mind as to just what features should be incorporated in the design of a suitable crane for doing the work in question.

It is impossible to design material-handling machinery which will handle a piano or automobile truck in one instance, and a can of condensed milk in another instance, and do both efficiently. It will readily be seen that it is impossible to develop a standard crane of any fixed radius and capacity to meet the varying conditions, hence it follows that efficient machinery of this sort most as a rule be designed and built to order.

The foregoing remarks are all of a general nature and apply to the general problem of material handling by mechanical means, and it would now seem desirable to call attention to the more specific points which must be kept in mind by a city such as Pittsburgh in developing its river terminals. In general, an efficient river terminal for Pittsburgh should be so designed and constructed that it will possess the following characteristics:

1. Provision must be made so that the operation of the terminal can be carried on with the level of the water of the river at any point between the maximum and minimum levels encountered throughout the year.
2. The water side of the terminal should be equipped with some semi-portal revolving jib-cranes, to the end that package freight picked up from the river steamers or lighters could be hoisted vertically the necessary height and then swung around and loaded upon railroad cars or trucks. This would involve the placing of railroad tracks and truck driveways within a horizontal distance of preferably 35 feet from the outer edge of the structure.
3. Means should be provided for conveying package freight, not loaded directly upon trucks or railroad cars, into the building and transporting it to a proper point of temporary placement.

The reverse movement should likewise be kept in mind. Let us follow for a moment a water shipment with a number of kegs of railroad spikes from a dealer in Pittsburgh to a customer in St. Louis. We will assume these kegs of spikes loaded on a motor truck, and the truck driven into a modern terminal located on the river here in Pittsburgh; and to complicate the matter we will assume that the spikes arrive at the river terminal the day before the river steamer is due. Under these conditions the truck will drive into the terminal, the crane for handling material within the building will pick up the kegs of spikes by the use of a magnet and deposit them in tiers at a suitable point, releasing the truck immediately. On the arrival of the steamer this crane, in turn, would pick up the spikes and land them outside of the building within reach of the revolving jib-crane which can be

used to load the steamer. This crane would likewise be equipped with a magnet and the kegs would thus be handled mechanically from the time of leaving the point of shipment on the Pittsburgh side to the time of arrival on the deck of the river steamer. On arrival of the steamer in St. Louis the shipment would be transferred from the ship to trucks in the reverse order with similar equipment, which, as you will readily agree, will involve a minimum handling cost.

The lack of material-handling facilities in this country was keenly felt during the war, primarily because it took so long to unload and despatch ships which were carrying to Europe the necessary provisions. You will appreciate this point when I state that a pier equipped with cargo-handling cranes, one for each hatch for the ships in question, can unload and despatch ships in six days as compared with 10 days required when ship's tackle is used. Furthermore, the cost per ton of unloading such a ship by means of cranes is about half the cost of unloading by means of ship's tackle.

Heyl & Patteron, Inc., of this city, were the first to realize the importance of, and to design and construct modern man-trolley bridges for, handling bulk materials, and in the same way they have been pioneers in the design and construction of cargo-handling cranes.

Mr. Morris Knowles:* Mr. Morse's excellent and timely paper shows that the problem of river regulation is tied up with all the various questions of waterfront improvements which are being discussed this evening. It shows how clearly interdependent, one upon the other, are the various projects and the various phases of community planning and river treatment, which will be helped materially by a comprehensive and broad-minded view of the entire subject. Just so it was shown in the Report of the Flood Commission of Pittsburgh, to which reference has been made by the author, that the erection of a large wall merely to protect land in Pittsburgh from overflow was a narrow proposi-

*President Morris Knowles, Inc.

tion. Although this would have been the cheaper project to the citizens of Pittsburgh directly, indirectly it would have failed. This is because it did not embrace the many beneficial effects which the reservoirs on the head-waters would have produced, not only at Pittsburgh but elsewhere on the streams, in regard to floods, navigation, water-power, water-supply, etc. Similarly, such construction of a large wall to prevent overflow would have resulted in an economic disaster to the city, because it would have prevented the proper development of its wharf, its railroad, street-railway and highway systems, etc. Likewise, in studying the hydraulics of river regulation, the pendulum must not swing too far in the other direction and conceive an ideal situation whereby floods would be entirely prevented by means of storage reservoirs, without supplementing them with some form of a river wall of lesser height. Even by a combination of reservoirs and river walls, it is not always wise or economically sound to attempt to make flood prevention 100 per cent. perfect and to prevent all overflow above the normal high water or pool-full line. It may be better to endure the damage of the seldom occuring floods, as long records show, rather than pay forever the interest on an excessive investment to prevent such rare occurrence. It generally pays—and Pittsburgh is no exception—to protect by local measures the lands that are subject to frequent overflow with annually recurring floods of not extreme height.

The construction of flood walls or barriers of moderate height in connection with river regulation often creates a marked improvement in the general convenience, pleasure, and esthetic appearance of a community. They reclaim, to a useful purpose, low-lying territory which is generally misused, frequently left to miscellaneous filling and very often the catch-all of detritus and waste. The building of protective walls means the cleaning of banks and such improvement may be made attractive with a boulevard or parkway development, so that ill-kept, unsightly banks, such as we have in Pittsburgh, may be changed and be of service. A good example of this, familiar to all, is the development along the left bank of the Susquehanna River at Harrisburg, where Front Street is one of the most attractive drives in

Pennsylvania. A similar situation obtains at Sunbury, Pa., where a boulevard on top of a levee provides a pleasurable detour and drive without passing through the business district.

Too often the building of bank walls is confused, in the public mind, with the question of river encroachment, and those not familiar with the hydraulics of stream flow often think that the construction of walls along the river tend to restrict the river channel, thus retarding the flood waters and increasing the flood height. This, of course, is not necessarily or usually true if vertical walls are constructed along the shore, particularly if the bottom is graded out in connection with the same improvement and thus an increased cross-section obtained. This stream discharge is then considerably increased over and above what the river flow would have been if the banks were not thus restricted and the river allowed to spread over the neighboring land. The reason for this is manifest to the student of hydraulics, because the hydraulic mean radius is greater and the friction of rough obstructing lands is removed and an even surface of a concrete wall substituted therefor.

In this connection, it may be remarked in passing, that the proposition advanced by some—that the proposed protection wall in Pittsburgh shall be columnar and open instead of a vertical plane—will defeat one of the purposes for which the wall has been planned. In the case of a parapet supported on piers there will be no additional carrying capacity for floods, because the opening would increase the friction over and above that which will result from a smooth vertical surface and the flow of water, in and out and underneath the wharf or arched wall, would of itself increase rather than decrease the resistance to the main flow of the stream. Another factor to be considered in connection with such an open structure is that detritus would collect under the wharf with every flood and the situation would soon become very objectionable with the accumulation of such waste material.

In its investigation of the flood wall, the Flood Commission of Pittsburgh made a number of studies based upon use with and without the construction of reservoirs on the head-waters of

the two rivers and with different amounts of dredging. These studies were made according to two general plans: first, with walls constructed along the present bank line of the stream; and second, with walls designed for a standard stream cross-section and running across certain minor curves and bends in the stream. The balancing factor against the expense of the greater cost of the wall was the credit to construction cost which would accrue from the value of the reclaimed lands. However, a wall following the present bank line, with but little dredging to improve critical places, was found to be the cheaper.

The height varies, in case of a wall following the present river banks, from an average of 14 feet, with reservoirs, to from 28 to 30 feet, without reservoirs, and the amount of land reclaimed varies from 7 to 52 acres. On the other hand, by the construction of a wall along the lines of a standard stream cross-section (although the wall varies from 28 to 34 feet in height depending upon the amount of dredging, and upon whether reservoirs are to be constructed or not) the amount of land reclaimed varies from 324 to 337 acres.

This wall, according to the recommended plan, was designed to take care of a flood stage two feet higher than that of the flood of 1907 when reduced by the use of reservoirs. It is to be supposed that in the course of a great many years, a flood higher than 1907 will occur, but it is reasonably certain that provisions for a disaster two feet higher than the 1907 stage will take care of a flood occurring in general not oftener than once in 20 years. With certain combinations of conditions, like the rain-fall of March, 1913, which produced the great Miami flood, the Allegheny drainage basin would produce a flood at least 10 feet higher than that of 1907.

The action of Congress involving river and harbor improvements, shows that the federal government is becoming more and more inclined to render financial aid for such improvements, only where it can be supplemented by monetary and constructive assistance from the local communities in helping themselves by the development of local facilities. As shown by the author, there is an increased understanding, that if river transportation is

to be made available to the public at large, and if consequent saving, due to the cheap transportation which is possible under proper river regulation, is to be secured, this can be accomplished only through a co-ordination of traffic between rail and water. Here in Pittsburgh we face an ever-increasing need of area for the accomplishment of business in the "golden triangle" and this, if for no other reason, should bring about a comprehensive study for the complete improvement of the city involving, as has already been pointed out, all the other phases of municipal development.

Many American cities are adopting plans for the comprehensive development of water frontage and the handling of river, rail, vehicular and other traffic. Pittsburgh seems to be the last. There is no one way to take care of our river front fully, but a vertical wall with a top which will provide wharfage, terminal facilities and level filling to provide parking for automobiles, and a widened street area for a boulevard for through traffic, are worthy of consideration. Conferences and studies by those who are most interested in these features of city development and in the use of the rivers should bring about an understanding in Pittsburgh, as it has elsewhere throughout the country, that river transportation will be improved and not injured by the proper carrying out of a comprehensive river program. This will include the prevention of and protection from floods, the development of power, and increase of water-supply, and general municipal improvement will be accomplished at the same time as a part of the same general comprehensive scheme. We should all get back of the authorities in the promotion of such a laudable enterprise.

Mr. J. M. Rice:* It is evident that if any of these plans for the development of the river front are carried out they are going to bring a much larger number of people to your river front, and when that occurs you will be confronted with the sewage problem. The sewage system of the down-town district unfortunately has to take care of not only the "golden triangle" but an area about twice that size. We have the Eleventh Street

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sewer coming down on the Monongahela side, and indeed there are fourteen sewers between the Point and Eleventh Street entering the Allegheny River and twelve on the Monongahela. While some of them are small, others are large and do cause some nuisance and menace. The number of people who are served by these sewers is surprising. From the report of the Transit Commission I find there are 280,000 to 300,000 people entering the triangle every day and there are probably 100,000 permanently employed there. There is a resident population of only about 3000. The resident population using the sewer system is about 11,000. That gives a large constant dry-weather flow of sewage into the river and this is vastly increased in time of storms, for our sewers are of the combined system, carrying both storm water and sewage.

We do have the problem of infiltration to some extent due to the rise and fall of the rivers. As to just how important this is I have not been able to obtain figures; but it is evident that just as soon as you start to develop you will have to face the question of co-ordinating that development with the collection and disposal of sewage. Two questions are involved in this— the elimination of nuisance at the outlets of sewers, and the general question of sewage disposal and treatment for the protection of the communities on the river lower down who may have to use this water for domestic purposes. In 1910 the State Department of Health issued a decree to the city of Pittsburg requiring it to prepare a plan for the collection and disposal of sewage. For two years the city authorities and four eminent consulting engineers worked on this problem and in 1912 brought in a report which did provide for the comprehensive collection and disposal of this sewage at a cost of something like $37,000,000 and recommended against it. Since that time there have been many discussions between state authorities and the city but nothing has been done. But we are drawing closer and closer to the time when some means of treatment will have to be supplied for this sewage, particularly that entering the river in the down-town section. The immediate solution of this prob-

lem, no matter what its ultimate solution, will be the building of intercepting sewers on both sides of the triangle along the rivers. This can be incorporated into any kind of quay wall at a great saving of cost over two separate constructions. In addition to the sewers proper they will require overflow chambers to take care of storm water, because it is not advisable to attempt to handle 500 or 600 gallons per capita. The storm waters can be discharged into the river. That will require brick chambers and pumping stations in times of high water to prevent backing up. And those pumping stations may be necessary at the lower end for treatment purposes.

As part of the immediate development we will need some form of submerged outlets into the river to distribute this sewage instead of concentrating it at a few points as at present. In the future we will have to add some form of treatment and that may possibly take the form of screening or possibly the activated sludge process. These processes require comparatively little space and it would seem to be the part of wisdom for the city in making any comprehensive plan to keep this in mind and provide space where these facilities could be placed. They can all be underground, and, if carefully thought out in advance, they might not interfere with any commercial or transportation facilities which have been discussed here. The sewers, however, are fixed by the laws of hydraulics and once established can not very well be changed; therefore in making any comprehensive plan it will be necessary to keep the sewage question in mind.

MR. HARRY J. LEWIS:* The first problem to be met in any improvement of river frontage is to secure in the channel a flow section which is as free as possible from obstruction along the sides, in order that we may be able to keep navigable water up to the work without great expense for dredging. The channel should therefore be kept down to an even width which will force it to scour clean in flood. This reduction of width is already in effect in the Pittsburgh district.

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The top of the wall or other improvement should be high enough so that when materials are lifted from river craft to any vehicle on shore, they should be practically on a level with the city streets. Not less than ten feet of water should be allowed for in front of the wall. These two elements make a fairly high wall in all cases and a simple gravity wall absorbs a lot of material.

There are three types of hoist which can be used to advantage on the river front—the revolving locomotive crane; the even-arm gantry, and the bridge crane. Each of these needs a track of from 16- to 18-foot gage as close to the edge of the wall as possible. In designing the support for the rear rail, which must be tied into the outer rail, all of this material can be used to reduce the outer section of wall.

This wide-gage track on the outer edge of a wall is probably the most elastic device that can be used as it will carry three types of crane and if any one of them is set on high legs, all shore vehicles may be brought to the outer edge of the wall with but little obstruction.

When a locomotive crane is used in connection with a bin on shore for handling bulk materials, its work is so rapid as to leave it a lot of idle time as compared with the older fixed hoists. This tends to stimulate a search for further uses in order to take up the idle time of the crane and thereby to increase the handling of materials to and from the river.

STRUCTURAL ENGINEERING PROBLEMS IN TRANSMISSION-LINE CONSTRUCTION

By James S. Martin*

It will be impossible within the limits of this brief paper to give a complete analysis of all the problems arising in connection with the planning and construction of lines for the transmission of electric power from the generating station to the consumer. It is not the purpose to go minutely into the principles governing the location of lines, or into the electrical problems involved, except as they bear relation to the structural and mechanical features.

One of the great problems in any industrial section is the generation of power and its transmission to the points where it will be converted into light, heat, or mechanical energy. If the power-station is operated by steam, of course it must be located where fuel and water are easily obtainable in sufficient quantities and with as much assurance as possible against any interruption in the supply; or, if it is a water-power plant, it must be located where a sufficient supply of water, with a suitable fall, may be obtained. These conditions do not necessarily apply in the selection of a site for a factory which is operated by electric power. Factory sites are subject to so many other conditions that a site suitable for a power-plant may be utterly unsuitable for a factory.

In the days when each factory either produced its own power or was operated by steam, the location often had to be a compromise, with the result that neither the power nor the factory operation could attain its highest efficiency. With the rise of the big power-station, where economy in production of electric energy alone need be considered, comes the problem of economic and efficient transmission of that power to the points where it is to be used.

Where electricity must be transmitted for long distances, it

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is generally more economical to transmit it at a high voltage, and transform it to a lower voltage near where it is to be used, than to try to transmit it at a low voltage.

In transmitting power for comparatively short distances, lower voltages may be used, for which a simple pole line may be sufficient. This type of construction, while it should receive careful attention—more, in fact, than is usually accorded it—does not require the great amount of engineering necessary for the successful construction of a high-voltage line. As the voltage of the current transmitted is increased, new and varied problems arise, and a greater amount of engineering knowledge and skill are required to meet the conditions arising in connection with the proper designing and construction of a transmission line which will be safe and efficient.

The preliminary location of a high-voltage transmission line is regulated by the location of the central power-station and the location of convenient sub-stations for distributing the power to the customers. It is not our purpose to discuss the problems involved in this part of the work. So many purely business considerations enter into the selection of terminal points of a transmission line, that the subject lies outside the field intended to be covered by this paper.

After the terminal points have been determined, the matter of exact location of the line becomes a problem that should be entirely under the control of engineers. There are so many questions arising during the whole work, from the preliminary running of the line until the current is turned on, the solution of which is absolutely unintelligible to one not trained in engineering lines, that any attempt to handle these questions, except under engineering control, is certain to result in trouble.

The proper selection of a route for a high-tension transmission line is a matter that cannot be turned over to anybody and everybody. Many men who are considered good men in surveying for pole lines, never seem to be able to learn the art of selecting a line suitable for economical and efficient tower-line construction. In fact, with some men, it seems that their experience in pole-line surveying, spoils them for tower-line location.

Railroad location is another matter that is altogether different

from the problem of tower-line location. In selecting the course of a railroad, one looks for a line as nearly level as possible, which results in hugging the streams or valleys, to a large extent. In tower-line construction, a properly selected succession of hills and valleys is a big advantage.

In locating a pole line, one generally follows the boundaries of fields as much as possible, the difference in cost of setting poles in different places being so slight that the difference in the cost of the right of way is the dominating factor. If the voltage of the current carried is not too high, the pole line may advantageously follow a public road.

When constructing a steel tower line, the ratio between construction costs and right-of-way cost is so radically different from what it is in the construction of a pole line, that in most cases the cost of construction should receive the first consideration. Of course, cases arise where the price of a right of way in the most advantageous location is so exhorbitant that the greatest economy lies in a less desirable location of line, as considered from an engineering standpoint; but the point which the writer desires to emphasize in this connection, is that since the engineering and construction costs are the dominating factors in the economy of tower-line construction, it is necessary that the engineering force be in complete charge of the location of the line if the best results obtainable are sought.

Besides the ability to choose the proper location of a line, there is another trait which is absolutely necessary in a man who would be a success in the work of making surveys for tower lines. This is tact, more tact, and then some more tact. He must be a diplomat of the first order. In fact, he must be "wise as a serpent and harmless as a dove." A few impatient or indiscreet words, a little carelessness in tramping through fields, or picking a few apples or peaches without permission, may cost a lot of money in the construction of the line. He must also be a diplomat of a positive type as well as negative, to get the best results; that is, he must not only avoid giving offense, but he should be able to get the positive good-will of the property owners and their neighbors. This good-will is worth dollars and cents to the electric company.

Diverging for a few moments from the general trend of our thought, we wish it were possible to impress upon the property owners the utter folly of employing an attorney to look after their interests in specifying safety requirements to be incorporated in the right-of-way agreements. What does a man, who has had no practical engineering experience in dealing with mechanical and physical laws, know about conditions of safety which men with minds trained along this very line have taken years to learn? The laws of physics, mechanics and electricity are not subject to *habeas corpus, mandamus,* or injunction proceedings, as some of these attorneys seem to think, judging by requirements which they frequently write into agreements. One case comes to the writer's mind where, had the attorney's ideas been carried out, the property owner would have had fireworks all over his place as soon as the current was turned on. If the property owner thinks he needs a representative to look after his interests, he should hire an engineer. People generally would be better off if they spent more money on engineers and less on attorneys.

To return to our subject, it is impossible within the limits of this paper to give a complete description of all the points involved in selecting a good line, from an engineering standpoint. Many points are felt, rather than calculated; that is, one gets accustomed to the appearance of a good profile for tower-line construction, so that he will instinctively choose the better of two lines, without having to study out all the details involved.

It goes without saying that, other things being equal, the straighter of two lines is the better. Every turn is a point of hazard. For that matter, every tower is a point of hazard but this hazard is greater at the turns. Besides this, every turn is an additional expense. A man engaged in securing a right of way naturally wishes to turn aside when a property owner seems unreasonable in his demands. Sometimes this is necessary, but very often the demands can be met at less expense than the extra cost of making a turn. For rough calculations, when estimating the extra cost of a turn in the construction of a tower line for 66,000-volt transmission, using 0000 stranded hard-drawn, copper-wire conductors, the writer uses $500 under average conditions.

When it becomes necessary to make a turn, care should be taken that the turning point is not located down in a valley. There are two reasons for this. The first is, that a valley is a

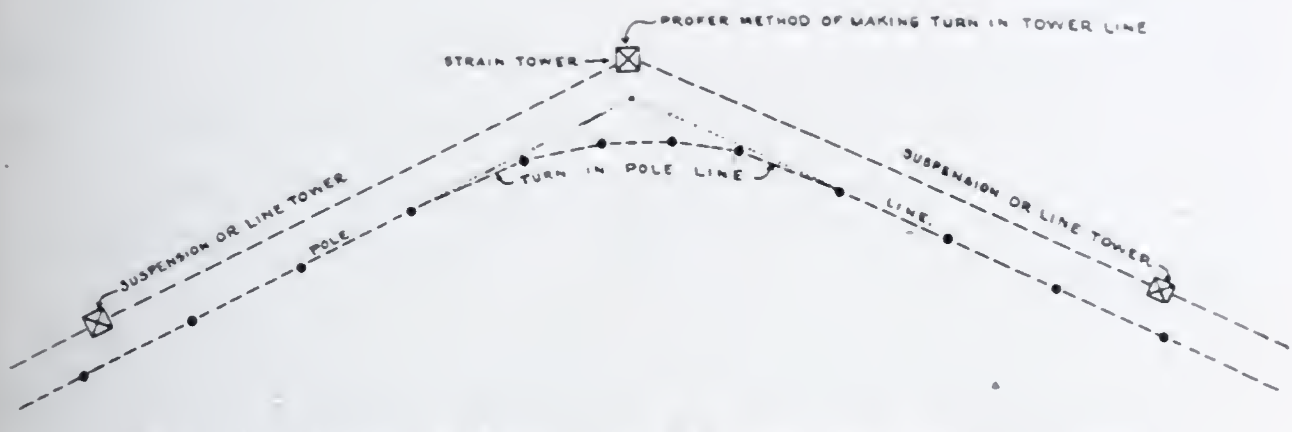

Fig. 1. Ordinary Method of Making Turn in Pole Line.

very poor location for a tower, because it makes it necessary to make the adjacent spans too short for good tower-line construction. The second is, that it produces an uplift on the arms of the tower. Most tower arms are designed with a view to sustaining weights downward, but with very little resistance to uplifting forces; and besides, in rainy weather, insulators turned up tend to catch and hold water, which is a detriment to their insulating qualities.

The tendency of surveyors trained in pole-line construction, is to ease off the turns, in a tower-line survey, as they would in

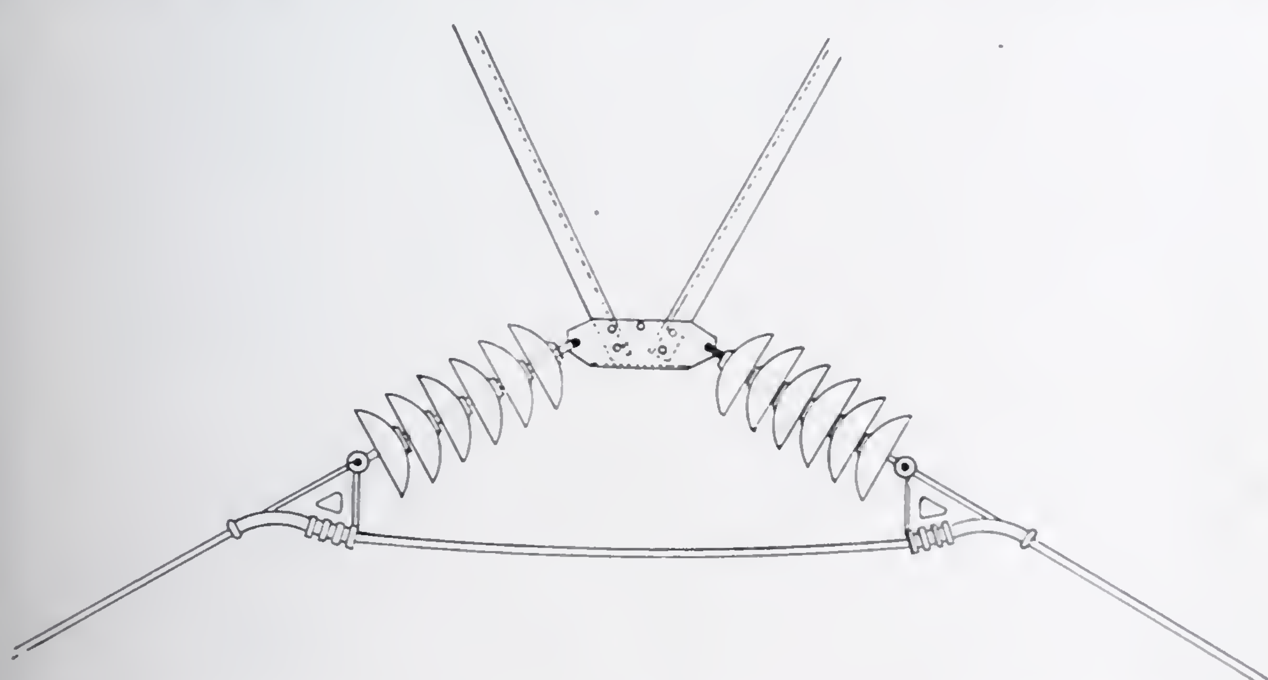

Fig. 2. Arrangement of Strain Insulators on Tower to Reduce Sharpness of Turn.

a pole-line survey; that is, they will make two or more turns a short distance apart, as shown in Fig. 1, instead of making the whole change of line in one turn. The towers are designed to take the full stress of the turn where they are used, and so there is no necessity for putting two towers in, for the purpose of gaining strength, while the arrangement of insulators in itself tends to ease off the curve, as shown in Fig. 2; and, besides this, the putting in of two towers generally results in having to use one or two more line towers than necessary, thus resulting in considerable extra expense.

Turns are seldom most advantageously placed when located on the exact top of the hill; at least, that is the case with the type of topography that we have in this part of the country. Fig. 3

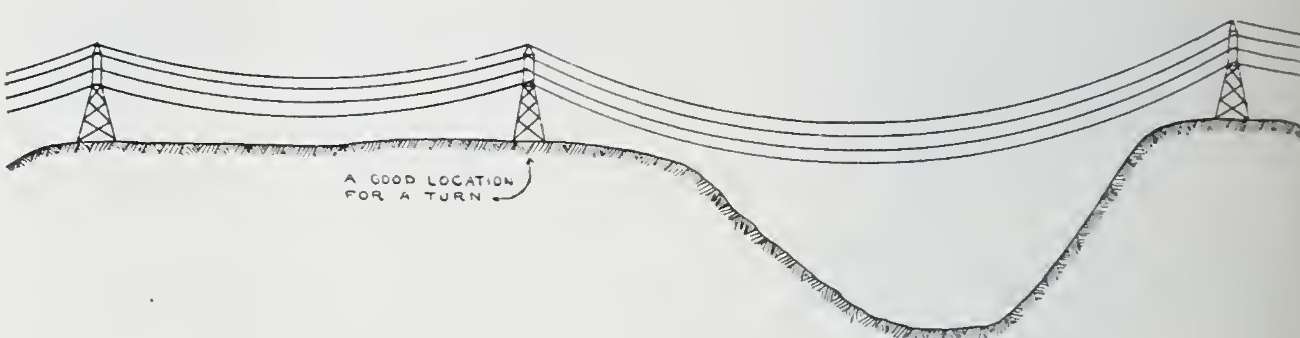

Fig. 3. Favorable Profile for Tower Line.

illustrates a good location for a turning point. You will notice that the turning point stands in a position that enables the tower to take the span from an adjacent valley, and to let the hilltop span pass over far enough to let the next tower take the next valley span. It should be understood that this represents an ideal condition which is not always possible of complete attainment, yet a skilled tower-line surveyor can accomplish this or a similar result in a large percentage of cases. In distinction from the railroad surveyor, the tower-line surveyor will hunt the hills and valleys, instead of a level stretch of ground. The valleys that are broad and deep with the sides not too abrupt but breaking away with a gently rounded shoulder to a comparatively level table land, before the next valley, are best suited for economic tower-line construction, the table land giving better advantages for hauling, erection, and wire stringing than abrupt hills and valleys. Fig. 3 shows a good profile for tower-line construction, while Fig. 4 shows one that is not so good.

Fig. 4. Unsatisfactory Profile for Tower Line.

It must be remembered that there are other conditions, such as accessibility, character of ground, etc., that must also be considered in this connection. The balancing of all these considerations, including the cost of right of way, will generally result in a sort of compromise location.

After the route has been selected, the definite surveys must be made. Plans of the line should be drawn, showing all property lines, fences, buildings within 150 to 200 feet of the line, roads, telegraph and telephone lines, and any other features, which may affect the construction of the line.

Notwithstanding all that may be said against "plane-table surveying" for this kind of work, the writer believes that, if tried, it would prove about the most satisfactory for this part of the work. It is almost impossible for any one to get all details exactly correct, when making notes in the book, lining up fences, etc., by sight, and then doing transcribing to plans in the office, where any items not definitely recorded must be supplied from memory.

In locating telephone or telegraph lines, the exact position of the nearest poles must be noted, and the name of the company operating the line—also the numbers (if there are any) on the nearest poles. In locating railway tracks crossed, the exact location of the crossing point with reference to the nearest milepost, or other permanent reference point must be noted and shown on the plans as drawn up.

After the plan is drawn up, a profile must be run over the line. While it is possible to run the profile at the same time that the plan survey is being made, it is usually better to have a separate corps run the profile, or else have the same corps go over the line for profile, after completing the plan survey. In running the profile, elevations should be taken at least every 100 feet, and oftener wherever the profile is not regular. In fact, an elevation

should be taken at every point where there is any break in the surface of the ground. Whenever the ground is sloping across the line, at a rate of more than one foot in 20, elevations should be taken on a line parallel to the running line, about ten feet from it on the higher side, in addition to the elevations on the running line. This is to make sure that proper clearances are provided for, under the wires on the higher side of the line. In taking the profile, the height of wires of all telephone, telegraph, or electric lines must be carefully measured. If in the line crossed, the wires are on a slope, their elevation at a point about ten feet to the upper side of the line must be taken. The elevations of rails of all railroads and electric lines, must also be taken. This is very important, as rules for clearance over railway and trolley lines are very strict.

Notes should be very clear, and plainly written. Questions frequently come up, five years or more after the line has been built, and often the party who made the survey is no longer in the employ of the company, and it is next to impossible for another to decipher the "hen tracks," which some surveyors leave in the note-books.

The writer is indebted to Mr. William F. Miller for the following item: The man in charge of the survey should keep careful notes of all damage done to crops or trees, during the work. All the men should be instructed to keep within as narrow limits as possible, while going through any cultivated ground, and the space tramped over should be carefully noted. The size of all trees cut down should be noted, the kind of tree and whether the tree was worth anything for lumber. Any damage to property should be carefully noted.

The reason for this is that the value of crops or trees takes a sudden rise, when they are destroyed by any agents of a corporation. Many farmers, who are otherwise considered honest, have no scruples against asking fifty to five hundred dollars for destruction of crops, the value of which by actual calculation does not exceed three or four dollars. A case occurred near Pittsburgh, where a man asked $500 and threatened to sue for it, where a very liberal calculation could not make the actual damage amount to more than 50 cents.

After the line and profile have been run, they should be carefully drawn to scale. The writer has found in his experience, that a profile drawn to a natural scale gives better satisfaction, in general, than one drawn to one scale for horizontal and another for vertical measurements. While this is contrary to the general practice, and the statement will probably be questioned by many, yet, when we come to discuss the question of methods of spotting towers, we believe that we will be able to give good and sufficient reasons for this opinion.

The question will naturally come up as to the scale to use, in making the plans and profiles. The writer has generally used 100 feet to the inch, and has found this very satisfactory. A smaller scale would be too hard on the eyes, and the possibility of errors would be too great; while a much larger scale would require too many breaks in the plan, in order to keep it on the tracing cloth, and would not allow the eye to grasp enough of the line at one time to get the best results in spotting towers. The man who is entrusted with the plotting of the surveys must be absolutely reliable, and must have an accurate eye, or serious errors may result.

After the plans and profiles are plotted, the towers must be located. While this subject might logically be considered the proper one to take up at this time, yet it is dependent also on the type of tower used, so we will turn aside for a while to take up the question of tower design.

Construction of towers in large quantities, for carrying transmission lines, is a rather recent development in engineering work. It is not more than 19 years since the beginning of quantity production of towers for transmission-line work. Among the first companies to use towers, were the Mexican Light and Power Company, and the Toronto and Niagara Falls Power Company. Other companies may have preceded these in the development of this method of power-line construction but, if so, the writer does not know of them.

At first, towers were designed by test, which method is still sometimes used. Modern methods of testing are a vast improvement over the first methods. At that time, the towers were erected in a horizontal position, against the side of a building,

and test weights were hung on them until they broke. If the tower stood up under a much heavier load than the load assumed in practice, a lighter tower was built and tested. This went on until a tower was produced, which would hold just a little more than the assumed maximum load it would get in practice. This method of erection, however, produced stresses which were entirely different from those which would occur if the tower were standing in its natural position. Consequently, this method was abandoned and frames were built, or other methods provided, whereby the towers could be tested while standing in a position as nearly as possible like that in actual practice, and the loads could be applied in directions approximating those which would occur when the tower was erected on the line and had the wires strung. The test method of designing towers, however, is being used less now than formerly. In modern practice, the stresses are generally determined by calculation or analysis in the same manner as for a bridge or other structure. This is a more satisfactory method, as towers which stand a test, carefully applied, often fail when placed in service under actual conditions. The rough and ready manner in which they are erected and the wires strung in the field will often cause tower members to give way, although they have stood up under a greater stress carefully and slowly applied.

The methods of calculating the stresses in towers are not radically different from those used in the calculation of stresses in any other kind of structure. Higher unit stresses are generally allowed than are used in bridge or building work. Even with this concession, the method of designing towers from calculated stresses will result in a design of tower heavier than when the tower is designed to stand a certain test, providing that the loads assumed in each case are the same. There is not as much loss from this extra weight as would appear at first thought. It adds to the initial cost of the line and in some ways makes erection more difficult; but, after the towers are once up, the freedom from trouble while stringing the wires, the added safety of the line during storms, and, especially, the added length of the life of the line, make the added initial expense seem a small matter.

The assumed loads, used in designing towers, have been

based upon a great many different theories. The first that occurs to a structural engineer, who is accustomed to consider the safety of structures which he is called upon to design, is the dead-end tower construction. This method of design is based on the assumption that the tower should be able to withstand the maximum pull which would occur if all the wires on one side of the tower were broken, leaving the wires on the other side unbalanced; and to take the maximum twist produced if all wires ended at the cross-arm and extended in opposite directions from opposite ends of the arm. This method, while it is safe, is so much more severe in its assumptions than any actual conditions which have any chance of occurring on a correctly constructed line, that the additional cost of building a line with towers such as these would not be justified by results. One such tower should be located every mile, to act as an anchor in case of accident to the line.

The next theory is, that a tower on the line should be built so as to be flexible. The idea in this method of design is that, as the tower yields to the pull of the wires, the sag of these wires is increased and the stress diminished to a point where the tower will resist it. This method of design results in a very light tower. If anchorage towers are used at frequent intervals and if the spans are short enough and of uniform length, the method will give fairly good service. This type finds its field of service in lines where latticed steel poles or very light steel towers are used to take the place of wood poles. As previously stated, where spans are small and uniform, this theory will work out, since a very slight variation in the length of the span, the length of wire remaining the same, will produce a very decided change in the sag. Where a real high-tension line is to be installed, and spans of good length are put in, this theory will not work out satisfactorily. As the length of span is increased, the sag must increase a little faster than the square of the span. It is obvious, then, that the ratio of sag to span is increasing. The percentage of excess in length of wire over the length of span is also increasing. The deflection of the tower is not producing the same effect in either quantity or percentage of stress in the wire and, long before the tower has deflected enough to make any material reduction in

the stress, it will collapse.

There is an economic mean between these two theories. The practice of the company with which the writer is connected, is to have three types of tower for regular line work. Besides these types, other types are used for river crossings or other special conditions.

The first of the three types is a suspension type, for straight line work. The type of insulators used on these towers is the suspension type, made up of five disks for 66,000 volts, and two disks for 22,000 volts or less. The swing of these insulators, when the wire breaks, is enough to make a very material difference in the stress in spans of fairly good length. The basis on which these towers are designed is that they are made strong enough to take any combination of broken wires, which would be at all likely to occur in a line properly designed and constructed. These towers are also expected to take a turn in the line of not more than five degrees.

The second type of tower is a strain tower, intended to take a turn in the line of from 5 to 45 degrees, or to act as a dead-end tower. Where the line runs for more than a mile without a turn, one of these towers is placed approximately every mile. This type is also used to support spans crossing railways.

The third type is the 90-degree type, which is used at turns of from 45 to 90 degrees. This type is also used on river crossings, where the height of tower required is within the limits of construction of this tower.

The loading for any type of tower depends on the type and size of wire used. The wire used in most of the work, with which the writer has been connected for the past few years, has been 0000 stranded, hard-drawn copper for general line work; and 0000 stranded, copper-clad steel for river crossings, and for spans where it becomes necessary to pull the wire up to a smaller sag than that required for the wire first mentioned. The hard-drawn copper which he has been using is slightly softer than the wire commonly known as hard drawn. Besides these, use has been made of some 0 stranded wire of both the hard-drawn copper and the copper-clad steel. This information is given to explain why examples given to illustrate points brought up in the course

of this paper, are generally based on one of these types of wire.

Coming down to practical application of methods of design, it is necessary to know the requirements which must be met. In referring to specifications, the following symbols will be used:

A, to refer to specifications of the National Electric Light Association.

B, to refer to General Order 13 of the Public Service Commission of Pennsylvania.

C, to refer to the National Electric Code.

B refers entirely to rules governing construction when a transmission line is crossing a railway, telephone line, telegraph line or other public utility; it is silent as to points involved in other parts of the line.

The first point is the determination of the maximum tension in the wires. A and B both specify, for conditions producing maximum tension, that the wire shall be considered as covered with ice, one-half inch thick, radially measured, and receiving a transverse wind pressure of eight pounds per square foot of projected area, the temperature being assumed as 0 F. C gives the same specifications for what is called "heavy loading," and also includes a medium equal to two-thirds the heavy loading, and a light loading equal to two-thirds the medium; but in no case shall medium or light be less than 125 per cent. of the weight of the bare wire. This part of the country being in what C specifies as the heavy-loading district, the medium and light loadings will not be considered.

The maximum permissible tension in the wire is one-half of the ultimate strength, according to A. The permissible stresses given by B are based on the same rule. The writer has not been able to find any rule on this subject in C.

In considering the requirements as to assumed conditions, supposed to represent the maximum conditions of stress liable to occur in practice, A requires that two wires be considered as broken where towers carry five wires or less; three wires broken, where 6 to 10 wires are carried; and four wires broken, where 11 or more wires are carried.

The line towers, which have been used for the past two or three years by the company with which the writer has been

working, are designed to resist the following assumed loads:

First, the line or suspension towers. These carry two three-wire circuits, and three ground wires. So far, in actual practice, only two ground wires have been strung.

1. A horizontal load of 1375 pounds at each of the nine wire supports—loads acting at right angles to the direction of the transmission line. Total load 12,375 pounds. This covers wind on the tower plus wind on the wires.
2. A horizontal load of 4000 pounds, in the direction of the line, at each end of any two cross-arms, or at one end of any four cross-arms. Total 16,000 pounds. This represents the stress due to four broken wires, the tension being reduced from the maximum pull on the wires on account of the swing of the suspension insulators.
3. A vertical load of 1500 pounds applied at each of nine wire supports. Total 13,500 pounds. This represents the weight of the wires.
4. The dead weight of the tower.

Second, the strain towers for turns in the line of from 5 to 45 degrees, or for dead ending the line.

1. A horizontal pull, in the direction of the line, of 4500 pounds at each of nine wire supports. Total 40,500 pounds. This represents the pull due to dead ending the wires.
2. A horizontal pull, in the direction of the line, of 4500 pounds at each of three conductor supports, at the end of the arms on the same side of the tower —loads acting in the same direction. Total 13,500 pounds. This represents the stress due to three broken wires.
3. A horizontal pull, transverse to the line, of 3450 pounds at each of nine wire supports. Total 31,050 pounds. This represents stress due to a 45-degree turn in the line.
4. A vertical load of 1500 pounds at each of nine wire supports. Total 13,500 pounds. This represents the

weight of the wires.

5. A horizontal load, transverse to the line, of 400 pounds at each of nine wire supports. Total 3600 pounds. This represents wind on the wires of the dead-end span.
6. Wind on tower, at 40 pounds per lineal foot of tower.
7. The dead weight of the tower.

Combinations of the above loading are taken as follows: 1, 4, 5, 6, and 7; 2, 4, 5, 6, and 7; or 3, 4, 5, 6, and 7.

Third, strain towers to take turns of from 45 to 90 degrees.

1. A horizontal pull, transverse to the line, of 6750 pounds at each of nine wire supports. Total 60,750 pounds. Stress due to a 90-degree turn in the line.
2. A horizontal pull, in the direction of the line, of 4500 pounds at the end of any cross-arm. This represents the dead ending of any wire.
3. A horizontal pull of 4500 pounds in the direction of the line, but in opposite directions, at each end of any cross-arm. Stress due to broken wires in adjacent spans.
4. A vertical load of 1500 pounds at each of nine wire supports. Total 13,500 pounds. Weight of wires.
5. A horizontal load of 1500 pounds at the top of the tower, in any direction. Wind on the tower.
6. The dead weight of the tower.

Combinations of the above loading are taken as follows: 1, 4, 5, and 6.

In figuring stresses for river-crossing towers, or other heavy service towers, heavier loads are used. The above loading is based on the use of stranded, hard-drawn, copper wire, size 0000, having an ultimate strength of 9190 pounds, while on river crossings, it has been the writer's custom to use 0000 stranded, copper-clad, steel wire having an ultimate strength of 11,960 pounds, in which case use is made of a safety factor of 2.5, which gives a working stress of 4800 pounds. The ultimate strength of 0000 stranded, copper-clad steel now produced is 14,300 pounds, which with a factor of 2.5 would give 5720 pounds as the working load. In

figuring a river-crossing tower, it is the writer's practice to consider the tower as dead ending all the wires on it, taking wind loads on the wires and on the tower, and resisting a twist due to all the wires in one span being broken on one side, and all the wires in the adjoining span being broken on the other side.

As to unit stresses allowed in steel, we quote from the specifications previously noted. A allows 18,000 pounds per square inch in tension; 14,000 pounds in shear; and 18,000 pounds—$60\frac{L}{R}$ for compression, with a limit to the $\frac{L}{R}$ of 180 for main members, and 220 for secondary members. It allows 10,000 pounds per square inch for shear; 20,000 pounds for bearing or bending, on rivets; 8500 pounds for shear; and 17,000 pounds for bearing and bending on bolts. These requirements are not followed in ordinary line construction. B allows 24,000 pounds in tension, 18,700 pounds in shear, and 24,000—$60\frac{L}{R}$ for compression, with limits of 180 and 200 for $\frac{L}{R}$ in main and secondary members. For rivets, bolts, and pins, 12,000 pounds shear, 24,000 pounds bearing, and 18,000 pounds bending are allowed. C allows 27,000 pounds per square inch for tension, 27,000 pounds—$90\frac{L}{R}$ for compression, and for bolts, rivets, and pins, 24,000 pounds shear, 48,000 pounds bearing, and 36,000 pounds bending.

In practice, the writer uses the values given by A for all river and special towers, except that he uses 12,000 pounds for bolts and rivets, and 24,000 pounds for shear and bearing. For the line or suspension towers used by the company with which the writer is employed, the following unit stresses are used: tension 27,000 pounds per square inch on net section; compression, 27,000 pounds—$100\frac{L}{R}$; shear on

bolts 20,000 pounds; and bearing on bolts 40,000 pounds per square inch. For strain or angle towers, the following unit stresses are used: tension, 25,000 pounds per square inch on net section; compression, 25,000 pounds—$95\frac{L}{R}$; and on bolts, shear 16,700 pounds; and bearing, 33,400 pounds per square inch.

Mr. J. B. Leeper of the American Bridge Company has worked out the formula for compression members, based on one-half the yield point as determined by test, as follows: 20,000 pounds—$85\frac{L}{R}$ for lengths up to 150 R, and 15,500 pounds—$55\frac{L}{R}$ for lengths over 150 R.

As to selection of sections, single angles should be used as much as possible. In regular line work, all or nearly all members can be economically made of single angles. On heavy duty towers, such as river-crossing towers or tall towers, sometimes it is necessary to resort to double-angle sections or other forms of built-up sections. For heavy post sections, the writer has found that a T-section composed of two angles and a plate gives about as good results in the long run as any other section. While other sections may appear better, theoretically, yet the elimination of gusset plates and other fittings, made possible by this section, more than makes up for the theoretical deficiencies, as to the economy of material in its main section. Above all things, avoid the use of lacing bars. After much study, the writer has come to the conclusion, that, except in a few special cases, the best place for lacing bars is the junk heap. In the first place, the lacing bars do not furnish effective material; that is, they are not counted on as furnishing additional section to the column, their service merely being to spread the section out so as to reduce the $\frac{L}{R}$. The writer has found, that in a very large percentage of cases, the material wasted in lacing bars, could be put into effective section, and the strength of the column increased, in spite of the increase in the $\frac{L}{R}$.

For general practice, the H-sections are very efficient substitutes for the latticed columns, it being generally possible to secure the same strength with less metal. In the second place, lacing bars take up more time and trouble in the shop than they are worth. In the third place, lacing bars are the greatest rust gatherers ever invented.

For these reasons, the writer has abandoned the use of lacing bars in any construction except the under sides of the top chords of bridges, and a few other places where their use can hardly be avoided. Of course, there are conditions arising in the design of very heavy bridgework where laced sections are necessary, but in those cases the bars are stiff members and bear more resemblance to web members in a truss than to the common lacing bar.

The anchorage of transmission towers may be in earth or in concrete. The writer's practice is to use earth anchorage for line towers and concrete for strain or angle towers. We recognize the fact that many companies have adopted the earth anchorage for angle towers on turns of less than 45 degrees, and some companies have adopted it for all towers; yet, after careful calculations based on actual results in the field, in setting earth and concrete anchorages and conceding every claim to the advocates of earth anchorages for towers of this sort, the writer finds that the concrete has such a wide margin in its favor, that he still believes in the concrete foundation for angle towers at turns of more than five degrees.

We will admit that an individual tower, selected for the purpose, may show an advantage for the earth anchorage; yet, in constructing a line, one is not dealing with individually selected towers but with the whole run of towers, good, bad, and in-between. In fact, in the making of these estimates, the writer included one tower that had been set incorrectly, and the concrete had to be broken and reset. This, of course, makes the case less favorable to the concrete; but, in estimating the cost of a line, accidents must be considered and the bitter taken with the sweet, so the cost of breaking and resetting the foundation was included in the cost of concrete foundations when the writer was making the comparison.

The reasons for the writer's opinion in this matter are as

follows. The only point in which the earth anchorage has any advantage is in the cost of concrete and forms. Earth foundations require more steel, larger and deeper excavations, and more backfilling. Besides these facts, the grillage for earth anchors practically has to be the same, whether the turn is 6 degrees or 45 degrees. It would cause endless confusion to have steel grillage constructed in as many different sizes as can be used in the construction of concrete piers. In the writer's practice, he uses a certain size of pier for turns of 5 to 15 degrees, another for 15 to 25 degrees, and so on, up to the greatest turns which the tower will take. As the stress on a tower taking a five-degree turn is less than on one taking a 30-degree turn, reason says that the anchorage should be modified to suit the conditions. In a tower made to resist a turn of 45 degrees in the line, if all concrete foundations were made heavy enough to take the greatest stress that would come on a tower taking the maximum turn, there is no doubt that the earth anchorage would have the advantage, but as the average turn is about 20 degrees or even less the advantage lies on the other side when the construction of the whole line is considered.

In addition, we would call attention to the fact that the excavations must go wider and deeper when using earth anchorage to make up for the loss of the weight of concrete. This may not seem to be such a disadvantage, but when we consider that in that extra two feet of depth we may have to go through solid rock, or may strike water (these are actual experiences), we can easily see that what little apparent advantage might be gained in a whole line by using earth anchorages may soon be offset in a few towers.

The writer recognizes the fact that there are many localities where the difficulty in obtaining materials for concrete would make it more economical to use the earth foundations; but, if this is not the case in this district where steel is most available, it would seem to the writer that under the average conditions to be found, the concrete foundations will prove the more economical.

In figuring anchorage, the usual practice is to figure the weight of the anchorage if it is of concrete, and the weight of the additional earth included in a solid figure the base of which is the area of the footing, and the sides of which slope outward as they

go up, at any angle of 30 degrees. Most specifications which the writer has seen, allow 140 pounds per cubic foot for concrete, and 100 pounds for good earth. The writer's practice is to use 150 and 90 pounds respectively, which will require anchorages a little heavier than the values before mentioned. In the case of earth anchorage, the earth is considered as sloping at 30 degrees to the vertical, and the weight of this prismoid-like figure is taken as the resisting weight.

As to the best form of earth anchor, there is a wide difference of opinion. There are as many forms as there are designers. Some forms are patented and some are not. All have advantages and disadvantages, and, without desiring to disparage in any way any form now on the market, the writer suggests that in his opinion, a strut around the bottom of the tower just above the ground line, and a channel bolted across the post angle a little below the ground (this channel being set across the two legs of the tower angle at 45 degrees to the axis of the tower and secured with a U-bolt) and a suitable grillage provided at the proper depth, would be as near to an ideal anchorage as could be obtained. The objection to this is the added cost of the strut around the bottom of the tower, but after consulting with erectors the writer is of the opinion that the saving in cost of erection would more than offset the extra cost of steel.

Two forms of concrete foundations are in use. The first that would suggest itself to a structural engineer, would be the common method of setting the base of the post on the pier, and anchoring it with anchor bolts. This method is used on many towers for heavy service. A method better adapted to towers on regular line work is the method of extending the posts into the concrete, and providing them with clips to furnish a good bond. In this case, the anchor stub should not be galvanized or painted below the line of concrete except enough to prevent water seeping down and rusting the steel. While 80 pounds per square inch is usually considered the bonding value between steel and concrete, the writer counts on only 50 pounds in calculating the bond between the anchor stub and the concrete. This reduction is made because the stub, which is usually an angle, does not give the concrete as good a chance to grip it as does the ordinary

reinforcing rod. The length of the anchor stub should be made sufficient to pass down through the pier and take hold of it at the bottom, with only enough concrete below to protect the steel. The depth of the anchorage should be determined by the limits of economy under average conditions to be met. The writer knows of no better way than the "cut and try" method. That is, by assuming certain depths, and calculating the average cost under the conditions to be met in the line under consideration, and taking that which shows up as the most economical. When the depth is determined, the stress, which is not provided for by the adhesion of the steel to the concrete, should be taken care of by bolting clips to the bottom of the anchor stub, allowing a good margin for safety. The anchorages on the compression side do not need to be as deep or heavy as on the tension side.

Other parts of the tower that need special care, are the head-frame and the cross-arms. Many designers, in their desire to get a light head-frame, produce a design that wastes more in the length of time required for erection than is gained in saving of steel. With a little more steel, the designer could make a head-frame which is easily erected. There are several easily erected

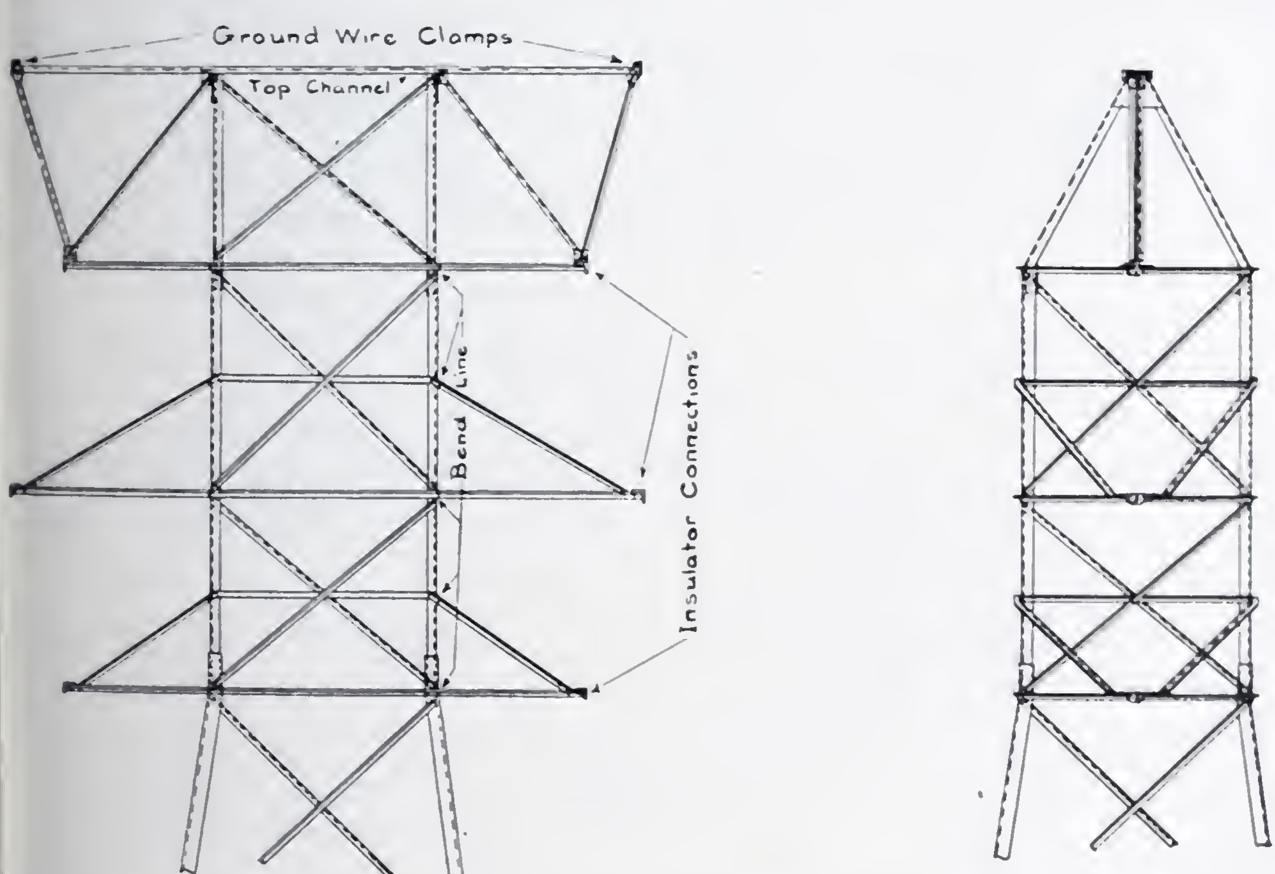

Fig. 5. One Type of Head-Frame.

forms of head-frames, and the writer presents one of these which erectors have mentioned as being quickly and easily erected. See Fig. 5. This is not given to disparage any other form, but only as one example of a form which is easy to erect.

The cross-arms are parts of the tower that are too often skimped in the design. There is no saving in a weak cross-arm. While a weakness in some other parts of the tower may be distributed over several different members and the tower thus saved from collapse, a weakness in the cross-arms is fatal. There has been a tendency to make the cross-arms too thin. Sometimes they are made as thin as 1/8 inch, but experience has shown this to be entirely too thin. The angle may seem to have a large enough radius of gyration and sufficient area to take the stress, yet the metal is so thin that the angle does not act as such, but resembles a folded piece of paper in the way it crumples when the load is applied. Another common point of weakness is the way the angles are often bent at the end to form a convenient connection for the insulators. This also should be avoided. Still another common weakness is the placing of a brace between the angles at the middle of their length, with the idea of dividing the length of the compression arm, but without placing diagonal braces between this brace and the body of the tower. As the compression arm shortens and the tension arm lengthens, the distance between the bolt holes would not remain the same if it were not for the brace; consequently, the brace tends to force the compression angle out of line, with the result that the arm collapses. Fig. 6

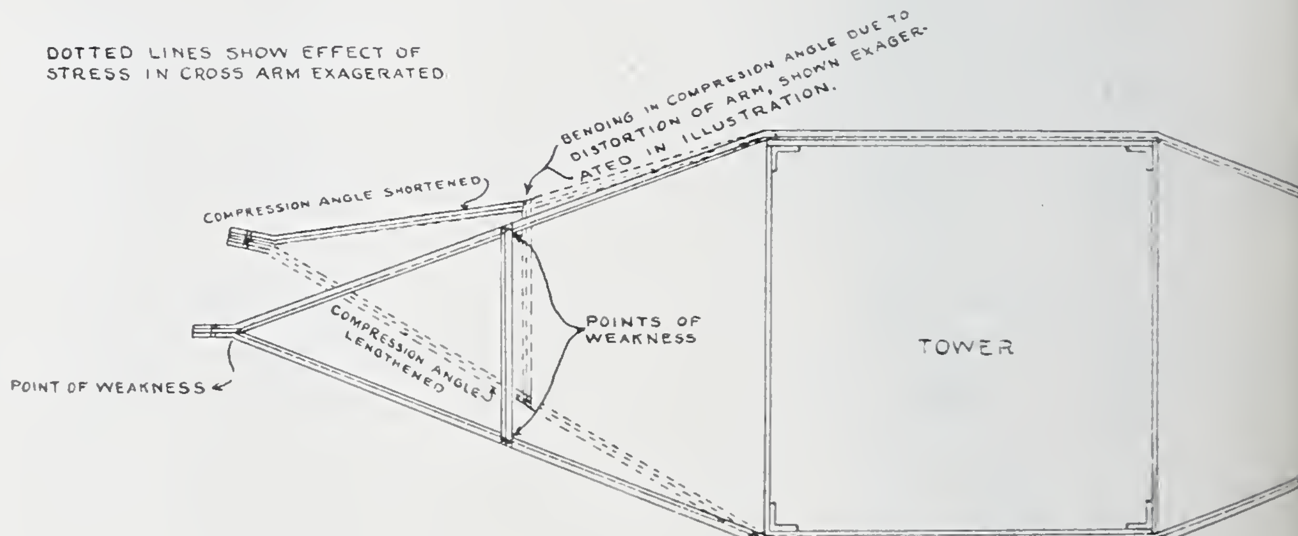

Fig. 6. Faulty Design of Cross-Arm.

shows a cross-arm of faulty design. The results of stress are shown exaggerated, in dotted lines. Fig. 7 shows examples

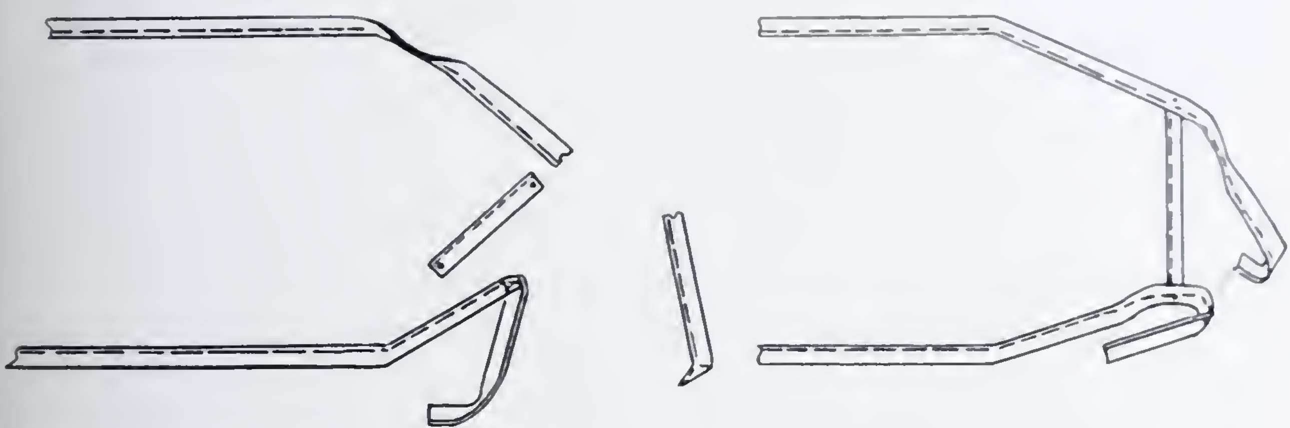

Fig. 7. Examples of Collapse of Cross-Arm Shown in Fig. 6.

copied from sketches in the writer's note-book, which illustrate the failure of arms of the design shown. You will note that the center brace is a point of weakness. To overcome the weakness shown up in the field by these cross-arms, the form shown in Fig. 8 was devised. These arms are made ¼ inch thick for strain

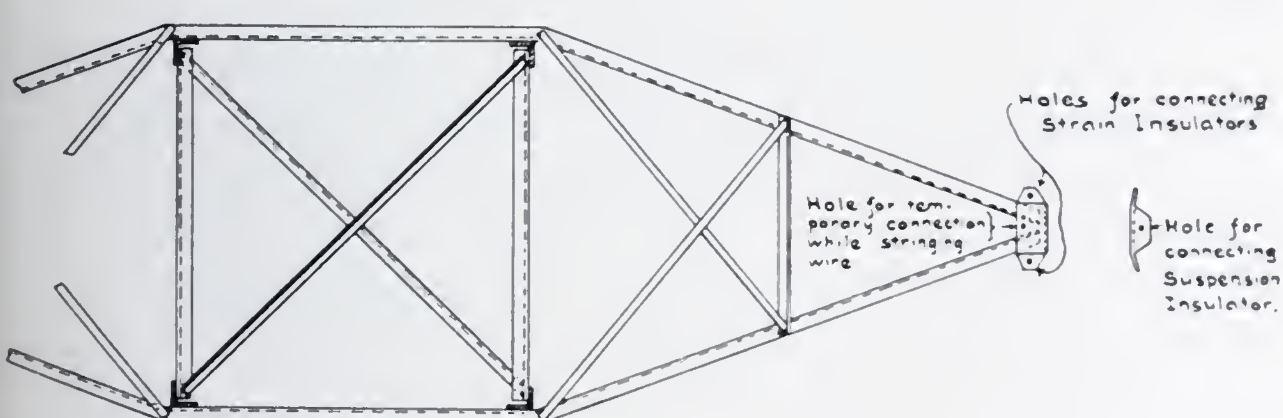

Fig. 8. Approved Type of Cross-Arm.

towers and 3/16 inch thick for suspension or line towers. The angles are left straight at the ends, and the insulator connection is made to suit either suspension or strain insulators. Besides these connections, there is a hole for connecting the blocks by which the wire is to be hoisted into place. This removes the temptation to hitch to the angles, which often results in putting a crimp in them before there is any strain in the wire. Our reason for making all connections ready for either strain or suspension insulators, is that it is our practice to use suspension

insulators for straight line towers and for turns up to one degree, except at railway crossings or where, for some other special reason, strain insulators are required. For turns of 1 degree to 15 degrees, we use what we call combination insulators; that is, we use strain insulators on the side of the tower on the outside of the bend, and suspension insulators on the side next to the inside of the bend, unless the clearance or limits of the right of way prevent, in which case strain insulators are used. Above 15 degrees strain insulators are used on both sides of the tower. The use of a different kind of connection for suspension and strain insulators required constant care, and even with the closest watching annoying mistakes crept through, so the policy was adopted of making all connections good for both types. This has proved a very satisfactory arrangement.

The supporting braces for the ends of the cross-arms should be made of angles for all strain towers and, while not so important for suspension towers, in designing them it would also be safer to use angles for these braces. The common practice is to make these braces of bars, assuming that they will always be in tension.

It often happens that a tower must be placed on a steep hillside where the line on the upper side slopes upward from the tower. This is an undesirable condition, yet cases occur where it cannot be avoided. If a wire on the lower side of the tower breaks, the uplift on the cross-arm will cause it to collapse unless the supporting braces are capable of withstanding compression.

Sometimes it happens that the conditions of the only right of way which it is possible to secure make it impossible to avoid the setting of a tower where the wires will produce an upward pull on the tower. In this case, if the upward tendency is very pronounced, the stringing of wires without collapsing the cross-arms is impossible unless the supporting braces are stiff members.

Another point to be watched in tower design, is to make parts interchangeable. For the slight difference that there is in the stresses in the faces with and across the line, the bother of keeping track of different sizes in the field makes it far more economical to make all faces alike, not only as to sections used but also as to the details. The connections for all anchor stubs should

be the same. The connections for extensions should be the same as for anchor stubs, so that when extensions are ordered there will be no need of furnishing special details of posts to take care of these extensions. In general, it may be said that it often pays to sacrifice a little in the matter of weight in order to gain in handling and erection.

As to protective coatings, there are two classes in general use. For the common run of towers, galvanizing is very largely used. This, if rightly done, is about the best method yet devised, and probably will be until a rustless steel is available. The galvanizing should be done to equal the requirements of the National Electric Light Association specifications. These specifications are so commonly given in handbooks that they will not be repeated here. The bolts for galvanized towers, should be Sherardized.

The other kind of protective coating is paint. The question of what constitutes a good protective paint for steel-work is a very broad subject, and one to which the writer has given considerable thought and study. It is impossible to go into a discussion of that subject here, further than to state a few facts which are agreed upon by all investigators.

There are three classes of paint pigments—inhibitive, indeterminate, and stimulative; that is, preventives of rust, those that are practically neutral, and those that stimulate rusting.

Those in the last class should never be used as a first coat. Among the most commonly used of these stimulative pigments, are graphite, lamp-black and carbon-black. These should never, under any circumstances, be used, where they will come next to steel. They make fairly good weathering paints, and may be safely used where there is a good coat of other paint between them and the steel, but the writer believes that, even there, it would be better to use a paint which would not be injurious in case the first coat is scratched off in places, as it generally is, by the time the steel is erected. The only reason that graphite paint has held its place so long, is that it can be thinned out and spread to an infinitesimally thin film, and yet be so opaque that it will still look like a good coat of paint.

For a first coat, a zinc chromate paint would be about the best to use, but it is usually considered too expensive. Red lead is

a good standard paint for a first coat, and, though it does not show such good preserving qualities as the zinc paint, it is considered a reliable protective paint.

For black paint, if that color is desired for a final coat, the writer would recommend a blend of willow charcoal and bone-black. As there ought to be three coats, the second coat ought to be of a color distinct from either of the others. "Prince's Metallic Brown," with a little red lead and willow charcoal, makes a good brown paint which is not too expensive.

Passing from these notes on tower design, we will next take up the question of locating towers along the line.

When the transmission-tower idea was first started, the lines were little more than metallized pole lines. The towers were spaced about 300 feet apart, and that was thought quite a distance. Gradually the length of spans was increased, until it is now recognized that spans of a mile in length can be used if the profile of the ground will allow it. Taking this district around Pittsburgh, if the engineering department has been in charge of the selection of the line, and has been allowed to place it where it should be placed, not much more than five towers to the mile should be required, and a great deal of the line can be put in at four to four and a half towers to the mile.

The fear of long spans is based on two ideas. The first is that the long span puts a greater strain on the tower and wire. The second is, that the great sag in the wires will cause them to swing together in a wind storm.

As to the first fear, if the web members in the four faces of the tower are all made alike and are heavy enough to stand the worst stresses on them, they will generally be strong enough to stand the extra stresses on them, including the extra stress due to the wind on the extra length of wire; but, if not, then a very slight increase in the weight of these, and also in the weight of posts, will make the tower strong enough to stand any side pull from the force of the wind on the extra length of wire. As to the stress on the wire itself, the sags are figured to give the same stress in the wire, under maximum conditions, for any span. Besides this, the stress in a wire of long span is more uniform than in a short span. If we take the case of a span of 300 feet

and one of 1000 feet, and a change in temperature of from 120 degrees to 0, then the change in stress in the short span will be 100 per cent., while in the long span it will be only about 10 per cent. As it is variation of stress more than quantity, within certain limits, that is injurious to the wire, it is seen that the long span will produce less damaging strain than the short one.

The next idea, namely, that the swing of the wires in the wind will cause them to swing together, is not well founded. The facts are that a long span with a large sag will not swing as much as a short span and small sag. Wind, in this locality at least, is not a constant quantity. It is constantly varying and, on a long span, the force at different points is not the same. The consequence is that the heavy wire in a long span does not get started to swing, as the puffs of wind almost never seem to synchronize with the period of oscillation of the wire, and men who work along the line during all kinds of weather declare that they have never seen the wire in one of our long spans swinging. In only one case have any signs been found that a wire in one of our long spans had been swinging, and in this case the wire was caught on the branch of a tree standing beside the line. We have spans of 1600 to 1800 feet in which the sag is more than 100 feet and the spread of wires 16 feet, and they have never yet swung together.

In addition to these considerations, it must be remembered that every tower is a point of hazard, for several reasons. Among these is the fact that every insulator is a point of possible flash over. Also, every tower is the point of maximum stress in the wire, while the gripping of the insulator clamp tends to weaken the wire at that point. The longer the spans, therefore, the fewer will be the points of hazard.

In selecting the locations for towers, the writer has found more satisfaction in using a profile drawn to a natural scale, than one drawn to a distorted scale. The reason for this is that the natural scale gives one a better grasp of what the real possibilities of the profile are. If merely locating towers at seven or eight to the mile were the only problem, the distorted profile would serve its purpose; but, when the object is to get the best and most economical location for these towers, the person spotting the

towers must have a complete grasp of the profile, and this the writer has never been able to get from a distorted scale.

The curve in which the wire will hang, being so close to a circular arc, within the limits that ordinarily occur in transmission-line work, and the small error in the circular arc being on the safe side, the writer has resorted to the use of circular curves in his work of plotting the profile of the hanging wires. These curves are the ordinary transparent celluloid circular curves, on which the clearance lines and the height of the standard towers, and of the towers with extensions, have been marked by lines parallel to the inside edge of the curve. By laying this curve down on the profile, approximate locations can be marked. For ordinary line work, using 0000 stranded, medium, hard-drawn, copper wire, the writer uses four curves—24, 25, 26 and 27 inch—the first for very short spans, the second for spans of 400 to 650 feet, the third for spans of 650 to 1000 feet, and the last for all spans of over 1000 feet. By a little practice, the operator will learn to select the proper curve by inspection of the profile. After tentatively marking the tower locations, the work should be carefully checked to see if it is possible to reduce the number of towers. This is a matter that will test the resourcefulness of the person doing the work. After one is satisfied that the number of towers is reduced to the minimum, then he should test the profile again to see if any extensions can be cut out or reduced.

Care should be taken to locate the towers so that the resultant of the forces, due to the tension in the wires pulling on the ends of the cross-arms, is downward. Any tendency in the wires to pull upward causes trouble, especially on suspension towers where the wires are apt to pull the insulators up against the cross-arms of the tower, causing a short-circuit. Sometimes wires which are strung in warm or mild weather are apparently all right until a cold snap comes, when the contraction of the wires causes trouble. If the towers are spaced as far apart as the profile of the ground will permit, this trouble will almost automatically disappear.

The length of span is affected by two other factors—the height of the tower, and the required clearance above the ground, river, railway track or other wires.

The height of towers now used by the company, of which the writer has been speaking, is 47 feet from base to the first pair of wires, seven feet to the next pair, eight feet to the upper pair of power wires, and seven feet from the upper power wires to the ground wires. In addition to the standard towers, 10-foot or 20-foot extensions may be added, giving increased height to the towers.

The minimum clearance allowed above the ground is 25 feet, but where this is less than the minimum required by the National Electric Safety Code, the clearance is increased to conform to the code. This code calls for 22 feet over a street or traveled way, 20 feet along roads in rural districts, and 17 feet for crossings over spaces or ways accessible to pedestrians only. These clearances are based on a current of 50,000 volts and must be increased by one-half inch for each 1000 volts in excess of this number. They must also be increased by one inch for each 10 feet in excess of 150 feet in length of span, till a 300-foot span is reached, after which they must be increased by one inch for each 20 feet of additional span length.

For clearance over other wires or over railways, General Order 13 of the Public Service Commission of Pennsylvania must be followed in this state. This order requires a clearance over public utility wires, of 0.1 foot for each kilovolt; with a minimum of four feet. To this must be added two inches for each 10 feet in the quantity obtained by adding the distance from the point of crossing to the nearest tower on the crossing line, and the distance from the same point to the nearest pole on the line crossed. For crossings over railways, this order calls for 26 feet plus the minimum separation between conductors, which is 60 inches for voltages from 47,000 to 70,000, with 0.6 inch added for each kilovolt over 70,000. This clearance is for spans up to 150 feet; for longer spans, the clearance must be increased by two inches for each 10 feet in excess of the 150 feet. The sags which allow these clearances, are to be taken at a temperature of 60 degrees F. with no wind on the wires. We would remark in passing, that general Order 13 also states that there shall be no ice load considered on the wires at 60 degrees temperature.

After the number and length of towers have been reduced to the absolute minimum, the surveying corps must again be called on to take the contour of the ground around each tower location. Contours should be taken for a distance of not less than 10 feet on each side beyond the outside of the tower.

From these contours, the exact elevation of the tower is determined, and it is also determined whether any hillside extensions are required, to make the base of the tower fit the ground. The hillside extensions used by the writer's company are as follows—six feet for the standard suspension tower, eight feet for the same tower with a 10-foot extension, and 10 feet for a tower with a 20-foot extension. These hillside extensions are made with either one leg or two legs extended. On the original towers two lengths were used for hillside extensions—5 and 10 feet. These were combined as follows—first, one-leg extensions of either length for all types of towers; second, two-leg extensions for all types of towers, both the legs of the extension being either 5 or 10 feet or one leg being 5 feet and one 10 feet. While this arrangement was somewhat complicated, and caused a little confusion at times, yet after considering the difficulties in fitting the later types to the ground, the writer seriously doubts whether the simplification noted above has been for the better.

Coming to the matter of the actual erection of the towers, the first matter is the excavation for setting the anchors. These excavations should be carefully laid out by engineers. There is a custom among some companies of simply making the excavations so big that the men setting the anchors are bound to have room to set them in place. This is a very foolish policy, as frequently the excavation is through rock; or it often happens that the work must be done in rainy weather, and it is necessary to make the time spent in excavating as short as possible, so that the anchors may be set quickly, to avoid the danger of the ground caving in around the excavation. The time and money spent in properly laying out the excavations is saved many times over in the construction of the line.

Fig. 9 shows the method followed in giving information to the men in charge of the laying out of the suspension towers. The drawing is made up as shown, and brown prints taken; not

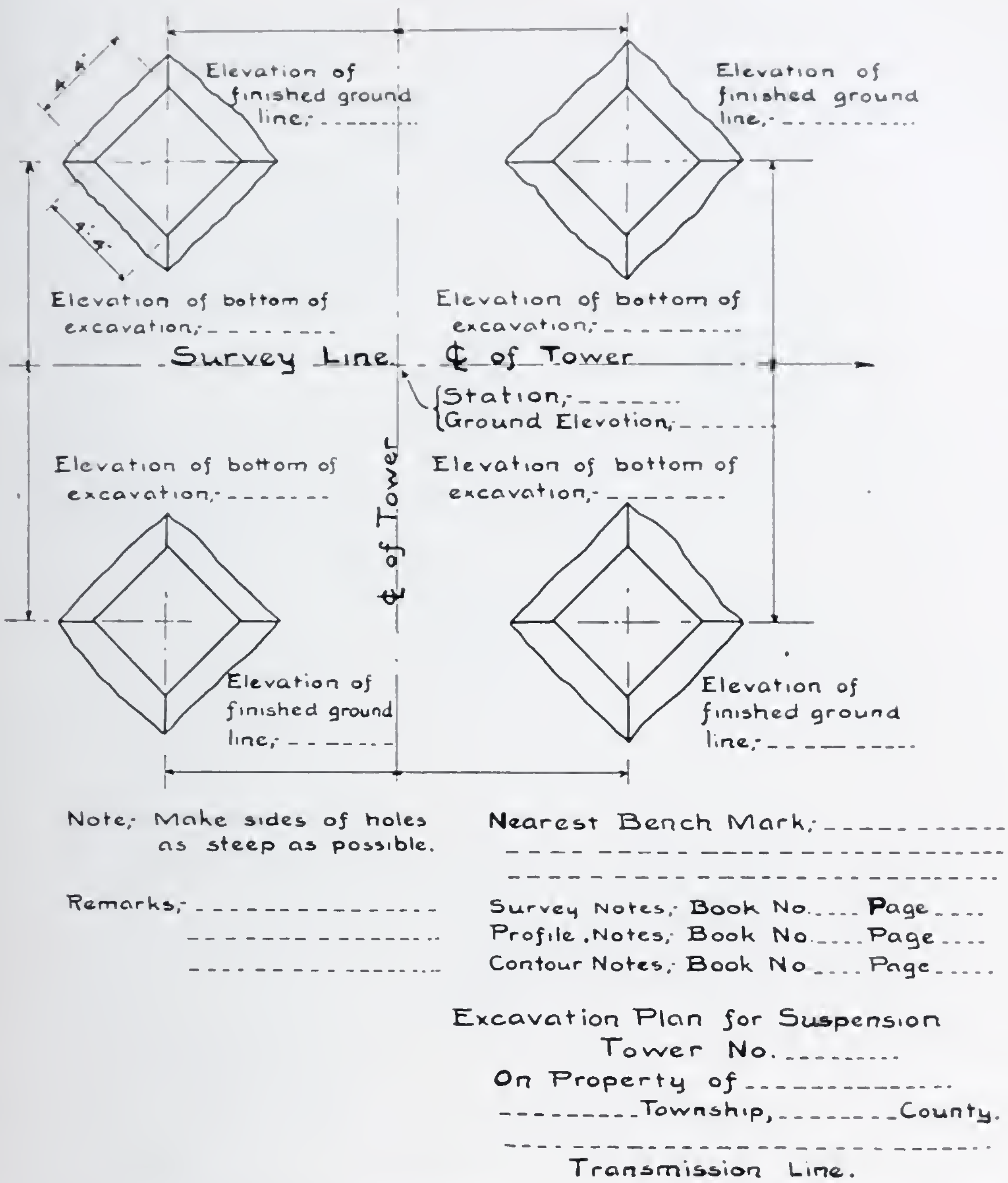

Fig. 9. Sample Blank Excavation Plan for Suspension Tower.

reversed as for a negative, but with the tracing right side up. The blanks on these prints are filled in, giving information for the tower, and blue-prints are taken off this and sent to the man in the field.

Fig. 10 shows the method of handling strain towers. The drawing is made up, omitting all dimensions which are not common to all towers of the type for which the foundation is designed. Negatives are then taken and white prints with brown lines are made. On these, the dimensions peculiar to the tower in question are filled in. These are used as drawings, blue-prints being taken off them and sent to the field.

All data should be given on these drawings, such as number

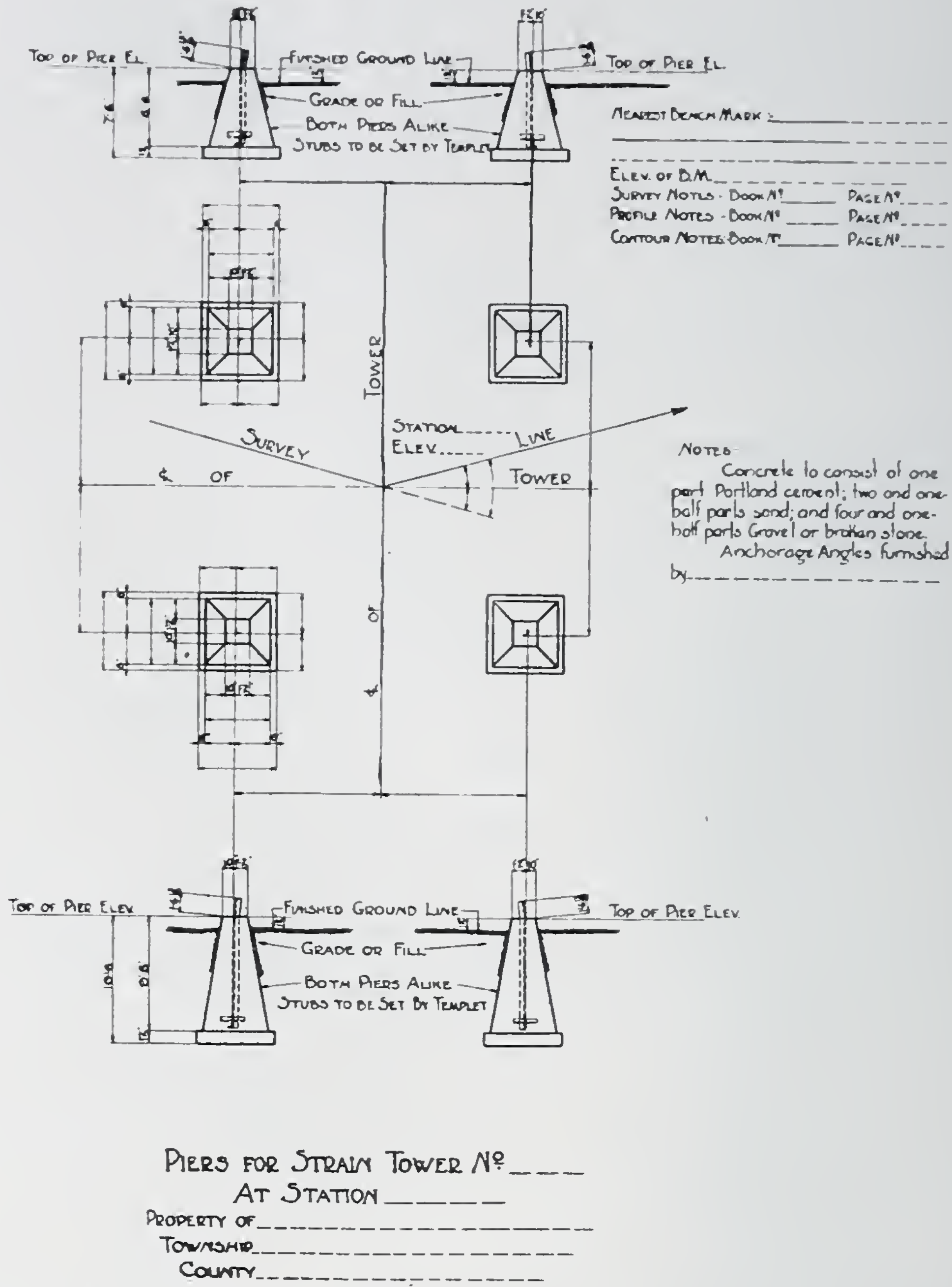

Fig. 10. Sample Standard Blank Drawing for Foundations of Strain Tower.

of note-books and page numbers on which the survey, profile and contour notes are recorded. The location and elevation of the nearest bench-mark should be given, and also any other information useful to the men laying out the tower.

The setting of the templet for spacing and holding the anchor stubs in place should be carefully checked. The back-filling after the stubs are set, or the concrete is in place, should be very thoroughly tamped.

The next step is the erection of towers. It is necessary that the towers be shipped as units; that is, the parts should be so arranged, in shipping, that an entire tower can be unloaded at

one place without breaking bundles or opening the boxes or bags of bolts or small fittings. In unloading the towers, the erection foreman or a very capable assistant should be present to see to the arrangement of the parts on the ground. This makes a very material difference in the cost of erection, making it possible to reduce the erection force by three or four men to a gang.

Three methods are used in the erection of towers. One is to assemble the tower on the ground, and then raise it to its upright position. The second is to assemble the parts of two opposite faces on the ground, raise these to position, and then fill in the remaining two faces in the air. The third, and the one most commonly used by our own organization, is to erect the tower in the air; that is, in its normal position.

Erection may be very cheap or very expensive, depending on the man in charge. The erection costs on a line built in 1919 averaged $13.30 per ton for work above ground. The work of setting stubs averaged considerably higher, and brought the average for all steel, above and below ground, to $17.86 per ton. Part of this work of setting anchor stubs was let out by contract, and cost considerably more than the work done by the company.

The sole purpose for which these towers are erected, is to enable the transmission of electric current. This leads to the consideration of the conductors and insulators.

The insulators in general use at present for this kind of work are of the disk type. In the earlier days of transmission-line construction, pin insulators were commonly used, but these have largely gone out of use for high-tension work.

There are several makes of disk insulators each having its strong and its weak points. The disks are connected together by means of fittings which are furnished with the insulators, and are catalogued by the manufacturers, so need not be described here. These insulators and their fittings should be thoroughly tested before the type is adopted; and, before they are sent from the factory, the insulators themselves should be tested to detect any defective ones. There are several ways of connecting the insulator strings to the tower. Some use a clevis and bolt; others use hooks. The writer prefers the latter method, and for river crossings, uses a double string of insulators connected by

yokes. Hooks may be made of forged steel or malleable iron, depending on the service they are expected to give. The design of hook should be thoroughly tested before it is adopted.

Fig. 11. Suspension Insulator String in Position.

Fig. 12. Strain Insulator String in Position.

Several views are presented, illustrating the methods of connecting the insulators. Fig. 11 illustrates a suspension string of insulators in position, showing the hook connecting it to the

Fig. 13. Strain Insulators in Position and Wires Strung.

tower, the clamp holding the wire, and the arcing horns. These arcing horns are for the purpose of saving the insulator in case of a flash over, by providing an easier path for the electric flash, than through the insulator disks. Fig. 12 illustrates a strain insulator in position, showing the hook, the clamp, and the

Fig. 14. Double String Insulators with Hook, Yokes, and Clamp.

arcing horn on the clamp. Fig. 13 shows the strain insulators in position on the tower with the wire strung. It will be noted that two makes of insulators appear in this picture, the one being light colored and the other dark. In this view, the jumper wire is shown, this being the part of the wire that passes from one clamp to the other, joining the two spans. Fig. 14 shows a double string of insulators, with hook, clamp, and yokes. Fig. 15 shows

Fig. 15. Testing Connections in String of Insulators before Installing on Tower.

the men testing a string of insulators before putting it up. This is not the testing of the individual insulators previously mentioned, but simply a field test to see if all connections have been properly made, before it is put on the tower.

Conductors may be of steel, aluminum or copper. Steel is the strongest and in many ways the best suited for this work as judged from a mechanical standpoint, and if properly galvanized it would last a reasonably long time, but its conductivity is so low —being only 17.4 per cent. that of soft-drawn copper—that it is not desirable as a conductor.

Aluminum is a better conductor than steel, its conductivity

being 60.5 per cent. that of copper, yet its strength is only 23,000 to 24,000 pounds per square inch, as compared to 34,000 for soft-drawn copper, and 55,000 to 60,000 for hard-drawn copper. Its modulus of elasticity is only 9,000,000 as compared to 12,000,000 for soft-drawn copper, 16,000,000 for hard-drawn copper, and 29,000,000 for steel. The coefficient of temperature expansion of aluminum is 0.0000128, as compared to 0.0000096 for copper and 0.0000068 for steel, per degree F. The melting point of aluminum is 1216 degrees, compared with 1981 degrees for copper. This means that, as compared with copper, aluminum is weaker, more easily stretched, more affected by temperature and easier to burn out when there is a short-circuit, besides being a poorer conductor. Thus it is seen that in the present state of our knowledge, copper seems to be in a class by itself as a conductor for transmission lines. There are two other forms in which wire is manufactured for transmission-line work. One of these is steel-reinforced aluminum, which consists of a core of steel—single strand in the smaller wires, or a stranded wire in the larger sizes—around which core the aluminum wires are wrapped.

The writer is somewhat in doubt as to the full efficiency of this wire. In the first place, there is no real bond between the two metals. The difference in the modulus of elasticity can be taken care of in the method of calculation, but no method has been devised to take care of the difference in the coefficient of expansion. It is evident that the two metals will work together at only one temperature, while at all other temperatures one or the other of the metals will be taking all the load. As the assumed conditions of maximum loading are based on zero temperature, and, as the wire is not manufactured at so low a temperature, it is evident that under maximum conditions the aluminum will attempt to take the whole load till it has stretched to the length of the steel at zero temperature. From that time on, the steel must carry the whole load, except when the temperature falls to zero or below. In view of this, it seems to the author that the only safe method is to consider the steel as taking all the load, in the same manner that a messenger wire carries a lead cable, and to calculate the sag of the wires on this basis. The construction of the clamps used with this wire are based on this principle; that is, the steel core is taken out of the center of the wire and run

into the clamp and secured, while the aluminum is continued over for a jumper, the steel core being replaced by an aluminum one. This method is safer also in case the wire is struck by lightning, or in case of a flash over. The aluminum strands are seriously damaged for a considerable distance, and often in locations where inspection is impossible, so that unless the steel core is strong enough to carry the whole load the wire is liable to break whenever heavy loading conditions occur. The method of considering the steel as carrying the entire load was employed in the design of a 5000-foot span for the Knoxville Power Company in Tennessee.

One other form of wire will be considered; that is, copper-clad steel. In the manufacture of this wire, the billet is made with a steel core surrounded by a copper jacket. This is rolled and drawn into wire, making a steel-cored copper wire. Three methods are used in the manufacture of this wire. One is that of inserting a bar of steel into a sleeve of copper, thus forming the billet from which the wire is drawn. If this process is properly carried out at the right temperature a welded joint between the copper and the steel will be secured. The second method is that of dipping a bar of steel into molten copper a number of times, till a coating of copper of the desired thickness is formed around the steel. This is then drawn into the wire. This produces a wire in which there is a true amalgamation between the metals, but it is difficult to make sure that the steel core is in the exact center of the wire, and also hard to make sure of the exact proportion of the two metals. The third method, and the one which the writer believes to be quite reliable, is that of setting a heated steel bar in the center of a cylindrical mold, and casting the copper casing around it. This billet is then made into wire of the desired gage. Tests have shown that the variation in the proportion between the two metals in the original billet and the finished wire is very slight.

The writer bases his calculations for this wire on the values given by the Copper Clad Steel Company, which are as follows. Breaking strength variable, depending on the size of the wire (definite information given in tabulation of properties of wires). Modulus of elasticity 20,000,000. Coefficient of expansion for

one degree F. 0.0000072. For stranded wire, the ultimate strength is taken as 90 per cent. of the combined strength of the individual wires. It may be mentioned, in passing, that this company has made the only tests of which the writer has any knowledge, to determine the true modulus of elasticity of stranded wires, but more will be said later on this subject.

At present, the main field for copper-clad wire is on long spans, where small sag is desirable, and for ground wires. Its conductivity is low—it being made in 30 and 40 per cent. conductivities—and so it can not as yet compete with copper wire for general line construction, but a new form is being put on the market, in which the conductivity is about 75 per cent. and this should enable it to compete with copper, due to the fact that the smaller sags possible would reduce the number of towers required, which would possibly reduce the cost of the line sufficiently to justify using a larger wire.

The subject of calculation of sags would be the logical one to take up here, but, as it is the intention to treat this as a special subject, the stringing of wires will be considered here.

As the wire comes in reels of about a mile in length, the unrolling and distributing of the wire is a matter for consideration. The line must be cleared of trees and underbrush before the stringing can be done. The reels of wire are taken out and set in the locations where they will be needed. A rope is attached to the end of the wire and drawn through pulleys attached to the towers. A rope a mile long is used by the company with which the writer is most familiar. The pulling may be done by horses or mules or by an engine. The adoption of the last method has saved the company a large percentage of the cost of stringing the wires. This engine is set up on the line and held in place by two bars, driven into the ground and lashed to the framework of the engine. The wire is thus distributed along the line. In pulling the wire up to the proper sag, horses or mules are still generally used, due to the fact that a gasoline engine can not start under a load, and this work requires the holding the tension for a considerable time, while making the adjustments to get the exact sag and while fastening the wire. The engine has however been tried on this work, and possibly with a little more experience it may

prove successful here also.

Three views illustrate the stringing of the wire. Fig. 16

Fig. 16. Engine Pulling up Cable.

shows the engine pulling the wire along the line. Note the method of anchoring the frame in place. Fig. 17 shows a team of horses

Fig. 17. Team of Horses Pulling up Cable.

pulling the wires up to the exact sag. Fig. 18 shows the method of splicing the wire. The wires from each end are run through a sleeve, which is just large enough to take the two wires. A wrench is applied to each end, and the sleeve and wires are twisted around until they are thoroughly spliced as you see in the picture.

One trouble which is experienced by nearly all companies,

Fig. 18. Wire Splice.

when starting out in transmission line construction, is that of getting the men in the field to understand that the suspension insulators do not need to hang plumb. For example, supposing we have a 300-foot span and adjacent to it a 1000-foot span. The temperature is 120 degrees in the hot July sun. There is a certain tension in the wire, which will be adjusted as nearly as possible by the swinging of the insulator. Now taking a zero day in January, the tension in the short span has varied 100 per cent. while the tension in the long span has varied only 10 per cent. It is evident that the suspension insulator will not hang in the same position to adjust the tension, that it did at a higher temperature. The suspension insulators will hang in a perpendicular position at a certain critical temperature, depending on the length of the adjacent spans, but at no other temperature. On our first line, the men who were stringing the wires, went over the whole line resagging the wires. They then reported to the office that the sag charts furnished were wrong. On being cross-questioned as to why they thought so, they said it was because the insulators were hanging out of plumb. The writer said, "You resagged the line in March, didn't you?" This being admitted, he continued, "Go back in August, and not one of the insulators will be hanging plumb." Since then our sag charts have the following note: "Insulators will not hang vertically except at certain temperatures. Insulators are to be held vertically till wire is properly sagged. After releasing them no readjustments are to be made

to make them hang vertically."

The question of the proper sags to give the wire, as stated before, should logically have come earlier in this paper, but as the purpose is to present some new methods of calculation connected with the tables which are presented at the last of the paper, the entire discussion has been deferred until this time.

When telegraph, telephone, or other forms of electric lines were strung on wooden poles, and spans were short, not exceeding 200 feet, the question of the proper amount of sag was not a very important one. It was simply considered a matter that could be left to the judgment of the workmen who were stringing the line. They merely drew the wire tight and then slacked it off a little, till it looked right to them. If a pole broke, or the wires came down in any way, the company owning the line, and any one struck by the falling poles or wires were simply out of luck. It was considered merely an act of Providence.

With the advent of higher voltages, when the cost of repair became a more serious matter and the danger to persons and property became a heavy liability, the companies owning the lines began to realize that the matter of determining safe sags for the wires and of stringing them to those sags, was not only possible, but a necessity. While at first it was thought that this calculation need be applied to heavy transmission lines only, it is now being more and more realized that it is safer to string the common pole lines in the same way.

Much has been written on the subject of the calculation of sags for wires, and it will seem at first that the writer is simply adding another method to an already numerous collection, but he has found the method herein described to possess so many advantages—which have been demonstrated in several ways, including competitive trials—that he believes the publication of this new method will be of advantage to the engineering profession.

The method devised by Mr. Percy H. Thomas, which he described in the *Transactions* of The American Institute of Electrical Engineers* in 1911, and which is also explained in the "Handbook on Overhead Line Construction," of the National Electric Light Association; also in the excellent work on "Transmission Towers," written by Mr. E. L. Gemmill of our own Society, and

published by the Blaw-Knox Company, will not be again explained here, as this paper is already longer than at first intended. The Thomas method is generally acknowledged to be the best yet published, and the writer has used it for a number of years; and in presenting a new method, he does not wish to detract one iota from the credit due Mr. Thomas as the inventor of an excellent method of calculation.

The difficulty which the writer has experienced with the Thomas method, is the impossibility of securing cross-section tracing cloth of sufficient accuracy for perfect work. The writer has two charts plotted from the same set of figures, these figures being calculated and checked to very much more frequent intervals than any which the writer has seen published. The plotting was done under a strong magnifying glass, and both charts are about six feet long; yet sags calculated on these two charts for the same span will sometimes vary by more than a foot. While this may not seem to be a very serious difference, yet the writer has one case in mind where the re-checking of a span by the method explained in this paper, saved $40 or more on one span. While the error in the readings from the Thomas chart was very small, as reckoned in percentage, yet the clearance requirements were very strict and the difference in the figures on the sag was sufficient to allow the foundations to be placed in a better location without the use of extended piers or the need of ordering additional steel. While this is an exceptional case, it shows what might happen.

But it is not chiefly on this basis that the writer presents his claims for the new method. The time element is one of the chief factors in determining the efficiency of a method. The writer confesses that his first results with the new method were a disappointment to him, in regard to the speed attainable. With a little practice, however, he was soon attaining as high a speed as he ever attained with the Thomas chart and in his first extended work while using the new method he was able to make from 50 to 100 per cent. greater speed than he ever made with the Thomas chart. Another point of advantage is that the tables presented are full enough to allow quick calculations to be made, when ex-

*Trans. A. I. E. E., v. 30, pt. 3, p. 2229.

treme accuracy is not needed, so that, as compared with the various approximate methods in vogue, more accurate results in the same or less time can be obtained.

Before entering into a detailed explanation of these tables and their use, it would be well to go over the underlying principles of sag calculation.

The first attempts to determine the true sag required in wires in a given span, to obtain definite results, were based on the assumption that the curve in which the wires will hang is a parabola. Many claim that the parabola is nearer to the true curve than is the catenary. Their argument is that the wire is not perfectly flexible, which is the assumption in determining the equation of the catenary. If the wire were perfectly flexible, the true curve would be an elastic catenary. However, the modulus of elasticity in the wire being so high in proportion to the weight of the wire, the difference between the elastic catenary and the common catenary would be very small; so small, in fact, that it is doubtful if it could be measured anywhere except in the laboratory.

If the wire were perfectly straight to begin with, and the flexibility of the wire were uniform throughout its length, and this flexibility a known quantity, then the true curve might be determined. But the wire is unrolled from a reel, and is always tending to twist itself up, and is subject to so many other indeterminate conditions, that it is impossible to determine the true curve.

The common catenary is probably the safest curve to base our calculations on, when figuring the sag to be given the wire. This curve is a tedious one to calculate, and for some of its characteristics the writer knows of no practical solution which is simple enough for common application. The chart devised by Mr. Percy H. Thomas, of which we have already spoken, is a graphical method of solving the problems involved. The method which the writer presents is a tabular method in which the functions are given at sufficiently frequent intervals to make interpolation practically accurate.

The basic assumptions for the calculation, are the length of span, the conditions of loading, the temperature, the allowed tension in the wire, the modulus of elasticity of the wire, and the

coefficient of temperature expansion in the wire.

The conditions of loading are explained on page 317 of this paper. In preparing tables or charts, giving sags for wire at different spans, the temperature is usually taken at intervals of 10 or 20 degrees.

In regard to the modulus of elasticity, one error in the published tables has persisted too long for any credit to the engineering profession; that is, the assumption that the modulus of elasticity of a stranded wire is the same as for a solid wire. It is almost self evident that they will not be the same, yet from year to year the assumption is made that they are.

The Copper Clad Steel Company has recently conducted some tests of seven-strand wire, showing that the stretch of a stranded wire may be as much as 20 per cent. more than for a solid wire of the same sectional area. The writer knows of no tests on 19-strand wire. In preparing the tables at the end of the paper, the writer has made the following assumptions, since he has no actual tests except those referred to. The first assumption is that the stretch of a 19-strand wire will bear the same relationship to the stretch of a solid wire of the same sectional area, as a seven-strand wire bears to its corresponding solid wire of the same outside diameter. In the absence of tests, we have to make some assumption in this case, and it has seemed to the writer that the advantage of having smaller wires in the strands would be offset by the fact that there are two layers of spirally coiled wires around the central core instead of one, so he has considered that this basis would be about as near the truth as any that he could think of. Actual tests may give different results from the ones obtained by this method, but it certainly is nearer the truth than the assumptions that have been made heretofore—that the modulus of elasticity is the same in a stranded as in a solid wire.

The next assumption is that the same curve plotted for the Copper Clad Steel Company's wire can be used for other materials. While this may not prove exactly accurate, yet it is as good a basis of calculation as the writer can think of until actual tests are made.

Before beginning the actual explanation of the use of the tables, there is presented a short analysis of what occurs in the

wire when under the different conditions of stress.

First, the wire is assumed to be loaded with the maximum loading of ice and wind, and under these conditions to be stressed to the maximum allowed tension. Under these conditions the wire is longer than the unstressed wire. If the temperature goes up, the expansion of the wire will cause an increase in the sag, which, within the limits of practical construction, will decrease the tension thus allowing a counter contraction in the wire, due to its elasticity. At a certain sag, these two tendencies will balance each other and the problem is to determine the point at which this will occur. In case the ice and wind load is removed, the decreased load on the wire will allow it to contract, which by decreasing the sag, increases the stress thus tending to increase the length and along with it, the sag. At a certain point these, as before, will balance each other. The problem then is to determine the unstressed length of the wire, from the length found for the wire hanging under maximum conditions; and, from that, to determine the unstressed length at other temperatures or under other conditions. Then, knowing the unstressed length, the amount of stretch and sag is to be determined.

While the mathematical demonstration of the methods involved in solving these problems would be of interest to those desiring to make a study of these problems, yet the space which would be required for such a demonstration would be more than could be spared in a paper of this kind.

There are two sets of tables. The first is based on the functions of the catenary, reduced to a form suitable for application to the purpose of the tables. The first column in this table gives successive values of the span multiplied by the weight per unit of length of the wire, and divided by the allowed stress in the wire. This column is given in intervals of 0.001, which makes it possible to obtain without interpolation results more accurate than by any of the so-called quick methods. The second column gives the sag, in fractions of the span, corresponding to the value in the first column. The third column gives the length of wire in terms of the span, for the corresponding value in the first column. The fourth column gives the stretch factor. This, the writer believes, is the first attempt to put in definite form

the actual value of the stretch factor. While in the low values the difference between the actual stretch factor, and the results obtained by assuming the wire to be stressed throughout its whole length at the maximum tension occurring at the points of support, is a negligible quantity; yet, in the longer spans, this difference becomes appreciable. If we neglect the reduction in weight per unit of length in the wire, due to the stretch under stress—which does not make any appreciable difference, within the limits of practical line construction—the total stretch in the wire will be the arithmetical mean between the amount of stretch which would occur in a wire equal in length to the catenary curve in which it is hanging, stressed to the maximum tension which occurs at the points of support; and the stretch which would occur in a wire as long as the span, stressed to the tension occurring at the mid or low point of the wire.

Since the variation in the stretch factor is so irregular as to make direct interpolation rather inaccurate in the first few pages of the table, there is introduced the fifth column, which consists of the products of the items in the first column multiplied by the items in the fourth column. The differences in this column are so regular that the values for points between the values given in the table can be found very accurately by direct interpolation. Then, dividing the interpolated value by the value used in the first column, the resulting quotient would be a very accurate interpolation for the stretch factor. For example, if the factor found for the first column is 0.1684, we find the value in the stretch factor column under 0.168 to be 5.9453636, and under 0.169 to be 5.9101005. By direct interpolation for 0.1684 we would get 5.9312584. Now take the values in the fifth column. For 0.168 we find 0.9988211, and for 0.169 we get 0.9988070. By direct interpolation, we get for 0.1684 the value, 0.9988155. Dividing this by 0.1684, we get 5.9312084. While for ordinary work, the difference between this value and the value 5.9312584, which was obtained by direct interpolation, would not be sufficient to make any material difference in results; yet, for very accurate work, and for work on very small spans (that is, while working with the first and second pages of the table) it is worth while to have the more accurate method for interpolating the stretch factor.

Those who have access to a Marchant or Munroe machine, will find these machines very handy and great time savers in the calculations necessary, especially if an extended series of calculations is being made.

The second table, or rather series of tables, gives the characteristics of the different wires in common use. In these tables, the first column gives the size of wire; the second, the assumed allowable tension under maximum conditions of loading. The first characteristic given is the weight per foot of wire under assumed condtions of maximum loading, divided by the allowed stress in the wire, represented by $\frac{w}{p}$ in the tables. This is given for heavy, medium, and light loading, as specified by the National Safety Code. The next characteristics given, are the weight of wire per foot, divided by the sectional area of the wire multiplied by the modulus of elasticity, or $\frac{w}{ae}$. This is given for heavy, medium, and light loading, for the unloaded wire and for wire loaded with a half-inch coating of ice, but disregarding wind. This we may call the elastic factor of the wire.

As the quickest and best way to explain the operation of the tables is by the actual solution of problems, we will proceed to show the methods of application in this way. We will first explain the more rapid approximate methods of applying these tables. When we speak of approximate methods, we are speaking only with relation to the more exact methods, explained later. As a matter of fact, these methods, here designated as approximate, while they rival the other approximate methods in common use in the speed with which results are obtained, will give results as accurate as those obtained by the use of the Thomas chart, and in most cases more accurate.

In these examples, and in the tables, the following designations have been used:

s. The span from tower to tower, in feet.

p. The allowed or assumed tension in the wire.

y. The ordinate in the Cartesian equation of the catenary.

w. The loaded weight of the wire under assumed maximum conditions.

w'. The dead weight of the wire, unloaded.

w''. The weight of the wire, with one-half inch coating of ice.

a. The sectional area of the wire.

e. The modulus of elasticity of the wire.

A few others will be introduced as occasion requires it, but they will be explained in the connection in which they are used.

FIRST PROBLEM

A medium length span. Span, 800 feet. Wire, 0000 stranded, hard-drawn copper. Loading, heavy, United States Bureau of Standards, National Safety Code. It is desired to know the sag under maximum conditions at zero temperature, and the sag of the unloaded wire at 60 degrees.

From the wire tables, the value of $\frac{w}{p}$ for this wire is found to be 0.00003282. Then,

$$\frac{sw}{p} = \frac{s}{y} = 0.0003282 \times 800 = 0.26256 \text{ (call it 0.263).}$$

For $\frac{s}{y} = 0.263$, we have the corresponding sag factor $= 0.0332134$. Sag under maximum conditions at zero temperature is $0.0332134 \times 800 = 26.57$ feet. The exact method, in which the sag factor is interpolated to correspond to $\frac{s}{y} = 0.26256$, gives a sag of 26.525 feet, thus showing that the approximate method in this case gives a result within one-sixth of one per cent. of the true value.

The length factor corresponding to 0.263 is 1.0029356.

The stretch factor from the sag calculating table is 3.7912556 (call it 3.7913).

The elastic factor for this wire loaded (from the wire tables) is 0.0000007572. The stretch is $3.7913 \times 0.0000007572 \times$ span (800 feet) $= 0.0022966$.

The unstressed length of wire is Length — Stretch, or 1.0029356 — 0.0022966 = 1.0006390. This length is at zero temperature. To find the length at 60 degrees we must add the expansion of the wire for 60 degrees, which is 0.0000096 × 60 = 0.000576. The unstressed length of wire at 60 degrees will be (1 + 0.000576) × 1.0006390 = 1.0012154.

The elastic factor for this wire unloaded (from the wire tables) is 0.0000002976. This, multiplied by the span, or 0.0000002976 × 800 = 0.00023808. This multiplied by the proper stretch factor, from the sag calculating tables, and the result added to the unstressed length, will give the length factor corresponding to that stretch factor. We can then tabulate the process thus:

Unstressed length of wire 1.0012154

(A glance at the table will show that the stretch factor should be between 4 and 5, as 4 × 0.00023808 added to the unstressed length would be less than the corresponding length factor, and the result using 5 would be greater than the corresponding length factor.)

First multiplication. 4 × 0.00023808 .... 0.0009523

First sum 1.0021677

(As the stretch factor nearest to the value 4 is 4.0056321, and the corresponding length factor is 1.00263 which is considerably more than the first sum, it will be necessary to add more to this sum. A mental calculation will show that 0.4 would bring the length factor too high, so we will use 0.3.)

Second multiplication. 0.3 × 0.00023808 .... 0.0000714

Second sum 1.0022391

(As these fall very close to the values corresponding to $\frac{s}{y} = 0.231$, we will complete the multiplication for this value of $\frac{s}{y}$, which has a stretch factor of 4.31933. We have already multiplied by 4.3)

Third multiplication. $0.01933 \times 0.00023808$ 0.0000046

Third and final sum 1.0022437

This, then, is the unstressed length plus the product of the stretch factor of the wire multiplied by the span, and that multiplied by the stretch factor corresponding to the value 0.231 for $\frac{s}{y}$, the result being very close to the length factor corresponding to 0.231 for $\frac{s}{y}$. As the difference between 1.0022437 and the length factor for $\frac{s}{y} = 0.231$ is about half the difference between the factors for 0.231 and 0.230, we will use the average of the sag factor, corresponding to $\frac{s}{y} = 0.230$ and 0.231, which is 0.0290392. This factor multiplied by 800 gives us 23.2313 for the sag at 60 degrees with the dead weight of the wire alone considered.

We would note that the sag as calculated by the exact method is 23.1760 feet, which shows the approximate result in this case is within 0.24 of one per cent. of the true result.

SECOND PROBLEM

The approximate method used on a short span. Strange as it may seem, the short spans are the hardest to handle with this method, on account of the rapid variation in the stretch factor in the first few pages of the sag calculating tables. While the percentage of error in the sag for short spans will be slightly higher than in longer spans, as calculated by the approximate method, yet the actual values are so small that the error is negligible, since it is impossible for men in the field to work so close to the figures.

Let us assume a span of 80 feet. Wire to be 0 soft-drawn, solid copper. Heavy loading considered.

Required, to find the sag at zero temperature under maximum loading; at 32 degrees under the same loading; and at 100 degrees with unloaded wire.

We find the value of $\frac{w}{p}$ for 0 solid, soft-drawn copper for heavy loading to be 0.0008671. Multiplying this by the span (80 feet) we get $\frac{s}{y} = \frac{sw}{p} = 0.069368$ (call it 0.069). The sag factor corresponding to 0.069 is 0.0086310. $0.0086310 \times 80 = 0.690$, which is the sag at zero temperature under maximum loading. The length factor for $\frac{s}{y} = 0.069$ is 1.0001986. The stretch factor for 0.069 from the sag calculating table is 14.4898775. The elastic factor for wire, from the wire tables, is 0.0000012203. Multiplying these together and by the span, we get for the stretch, $14.48988 \times 0.0000012203 \times 80 = 0.0014146$. The unstressed length of the wire is $1.0001986 - 0.0014146 = 0.9987840$, at zero temperature. The coefficient of expansion for copper is 0.0000096 per degree F. Then for 32 degrees the expansion would be $0.0000096 \times 32 = 0.0003072$. The unstressed length of wire at 32 degrees would be $(1 + 0.0003072) \times 0.9987840 = 0.9990908$. Since the loading conditions are the same as at zero, we use for the wire the same elastic factor that we did for zero temperature (0.0000012203). Multiplying this by the span (80 feet) we get 0.000097624, which is the factor to be multiplied by the stretch factor from the table, to find the stretch of the wire in terms of the span.

Proceeding as before:

Unstressed length of wire 0.9990908

(Looking at the tables, we notice that 10 times 0.000097624 added to the unstressed length, would be less than the length factor corresponding to 10 in the stretch factor column—see bottom of second sheet of tables—while 20 times the same factor, added to the unstressed length, would give too high a length factor.)

First multiplication. 10×0.000097624 .... 0.0009762

First sum 1.0000670

(Inspection shows that 3 would be too much for the second digit, while 2 is a little under the required amount.)

Second multiplication. 2×0.000097624 ....0.0001953

Second sum 1.0002623

(A look at the tables shows that the final result will come close to the values corresponding to $\frac{s}{y} = 0.082$, since completing the stretch factor for $\frac{s}{y} = 0.083$ and adding to our length, would fall short of the corresponding length factor, while doing the same for $\frac{s}{y} = 0.081$, would give too high a value for the length.)

Third multiplication. $0.1917029 \times 0.000097624$ (making a total of $12.1917029 \times 0.000097624$, corresponding to the stretch factor for $\frac{s}{y} = 0.082$)........0.0000187

Final sum 1.0002810

This is very close to the length factor corresponding to $\frac{s}{y} = 0.082$. The sag factor for $\frac{s}{y} = 0.082$ is 0.0102601. Multiplying the span by this factor gives us 0.8208 feet, which is the sag at 32 degrees, the wire being loaded with a one-half inch coating of ice, and sustaining an eight-pound wind.

The last multiplication, in the list just given, is really unnecessary in practice, as inspection would show after the second addition that the value of $\frac{s}{y}$ is very close to 0.082, without further calculation.

We will now determine the sag for the unloaded wire at 100 degrees temperature. The unstressed length of wire at

zero = 0.9987840. The expansion for 100 degrees = 100 × 0.0000096 = 0.00096. The unstressed length at 100 degrees is (1 + 0.00096) × 0.998740 = 0.9997428. The elastic factor of unloaded wire (0 soft-drawn, solid copper) from the wire tables, is 0.0000003217. This multiplied by the span (80 feet), gives us $0.000025736 = \frac{w' s}{ae}$.

Unstressed length at 100 degrees	0.9997428
First multiplication. 10 × 0.000025736	0.0002574
Second multiplication. 6 × 0.000025736	0.0001544
Third multiplication. 0.12644 × 0.000025736	0.0000033
Final sum (first and second sums not noted, having been previously explained)	1.0001579

The stretch factor used then was the sum of 10, 6, and 0.12644 = 16.12644, or the stretch factor corresponding to $\frac{s}{y}$ = 0.062, while the resultant length factor comes nearer to the value corresponding to $\frac{s}{y} = 0.062$, than to any other, so we use the sag factor corresponding to the same value for $\frac{s}{y}$ (0.0077544). The span (80 feet) being multiplied by this factor gives a sag of 0.620 feet, with unloaded wire at 100 degrees.

There is a method, which is sometimes easier, which can be applied when $\frac{ws}{ae}$ is less than 0.04 × (1 — unstressed length of wire), if the unstressed length of the wire is less than unity.

Taking this same problem, to find the sag for the unloaded wire at zero temperature. We have the unstressed length as previously worked out, 0.9987840. Then 1 — 0.9987840 = 0.0012160. Also, $\frac{ws}{ae}$ = 0.0000003217 × 80 = 0.000025736. Dividing 0.000025736 by 0.00121600 we get a quotient of 0.021165, which being

less than 0.04 shows that the method is applicable.

Taking this quotient (0.021165) we square it and divide by 24 and get 0.0000187. Add this to the value, 0.0012160, obtained above, which gives us 0.0012347. We now divide the value 0.000025736 again, this time by 0.0012347 and get a quotient 0.02084 (call it 0.021), which is approximately the required value of $\frac{s}{y}$. The sag factor for $\frac{s}{y} = 0.021$, is 0.0026251. Span (80 feet) $\times$ 0.0026251 = 0.210 feet, which is the sag at zero temperature with unloaded wire.

THIRD PROBLEM

One more example of the application of these tables by means of the methods we have chosen to designate as approximate, as distinguished from the methods which produce results as accurate as figures can give.

In this case we will assume a long span of 4500 feet. Wire to be ⅝-inch, seven-strand, copper-clad steel wire. Heavy loading.

Find the sag at zero temperature with maximum load, and sag of unloaded wire at the following temperatures: zero, 20 degrees, 40 degrees, 60 degrees, 80 degrees, and 100 degrees.

As before, we look up the value of $\frac{w}{p}$ for this wire from the wire tables, finding it to be 0.0002013. This multiplied by the span (4500 feet) gives us 0.90585 as the value of $\frac{sw}{p} = \frac{s}{y}$. We will call this 0.906.

The sag factor corresponding to 0.906 is 0.1314139. Multiplying this by the span (4500 feet) we get for the sag 591.362 feet. This is at zero temperature with maximum loading. Accurate calculation of the sag gives us a sag of 591.228 feet, showing that the approximate result in this case is within 1/40 of one per cent. of the true value.

The length factor corresponding to $\frac{s}{y} = 0.906$, is 1.0446574.

The elastic factor for $\frac{s}{y} = 0.906$, is 1.0626912.

The stretch factor for wire with heavy loading,

$\frac{w}{ae} = 0.0000005228.$

The stretch $= 1.0626912 \times 0.0000005228 \times$ span (4500 feet) = ...0.0025001

The unstressed length of wire equals the difference 1.0421573

The coefficient of expansion for copper-clad steel is 0.0000072.

The expansion in wire, the length of which is 1.0421573, for 20 degrees rise in temperature is $1.0421573 \times 0.0000072 \times 20 =$ 0.0001501.

Adding this successively to the length of wire, we will have the following unstressed length for the different temperatures:

1.0421573 at 0 degrees.
1.0423074 at 20 degrees.
1.0424575 at 40 degrees.
1.0426076 at 60 degrees.
1.0427577 at 80 degrees.
1.0429078 at 100 degrees.

The elastic factor for ⅝-inch, seven-strand, copper-clad wire is 0.0000002340. This times the span (4500 feet) = 0.0010530. We will select one of the length values given above, from near the middle of the list, and work both ways from it. This is a little more accurate than to work from one end of the list. In this case, the span being so long, it will not make any material difference which we take, the length at 40 or 60 degrees; but, if the span were 1000 feet or near that, the length at 40 degrees would give slightly more accurate results. For this reason we take the lower of the two temperatures, which is 40 degrees.

Without explaining each multiplication as we did before, we will tabulate the results as follows:

Unstressed length at 40 degrees 1.0424575
First multiplication. $0.0010530 \times 1.0000000$ 0.0010530

First sum 1.0435105

Second multiplication. 0.0010530 $\times$ 0.0700000	0.0000737
Second sum	1.0435842
Third multiplication. 0.0010530 $\times$ 0.0029581	0.0000031

Final sum. Stretch factor = 1.0729581. Length = 1.0435873

This stretch factor corresponds to the stretch factor for $\frac{s}{y} = 0.898$, while the length factor is slightly less than the length factor for that value, being considerably nearer to the value for 0.898 than for 0.897, so we will take the sag factor for 0.898 (= 0.1298220) which multiplied by the span (4500 feet) gives us a sag at 40 degrees, with unloaded wire, of 584.199 feet.

To find the change in sag for each change of 20 degrees in temperature, we can figure for each temperature in the same way as we did for 40 degrees, or we can take the following short cut.

The difference between the stretch factors for $\frac{s}{y} = 0.897$ and 0.898 is 1.0742536 — 1.0729581 = 0.0012955, which multiplied by the factor 0.0010530, which we have been using, gives us a change in stretch, for a change of 0.001 in the value of $\frac{s}{y}$, of 0.0000136. As this is a negative change, it works against the increase in the corresponding length factor. It would require a change in the unstressed length of the sum of the negative change in stretch and the positive change in length factor to account for a change of 0.001 in the value of $\frac{s}{y}$. The difference in length factor between the values 0.897 and 0.898 for $\frac{s}{y}$, is 0.0001290. Hence 0.0000014 + 0.0001290 (= 0.0001304) is the required change in the unstressed length to account for a change of 0.001 in the value of $\frac{s}{y}$.

We have seen that the change in unstressed length for a change in temperature of 20 degrees is 0.0001501. Then 0.0001501 ÷ 0.0001304 = 1.1511. Since the change in sag factor between these points is 0.0001978, the change in sag for each change in temperature of 20 degrees would be, 0.0001978 × 1.1511 × the span (4500 feet) = 1.025 feet. Adding this value to or subtracting it from the sag at 40 degrees, we get the following tabulation:

Sag at 0 degrees = 582.149 feet.
Sag at 20 degrees = 583.174 feet.
Sag at 40 degrees = 584.199 feet.
Sag at 60 degrees = 585.224 feet.
Sag at 80 degrees = 586.249 feet.
Sag at 100 degrees = 587.274 feet.

These results are more accurate than those obtainable by the Thomas chart, and are within about 0.05 of one per cent. of the true values.

We would caution the reader to use care in applying this last method of determining the sags for several temperatures, from one figured temperature, when working with sags which give values found on sheets near the first part of the table. For values falling in the first three sheets, the sag for each temperature should be figured, or at least given a back check. Even on these sheets, however, the error would not be as great as will occur in most of the approximate methods in common use.

We now come to the consideration of the more exact methods of applying this system of sag calculation. The principal difference between these methods and those which have just been described, is that in the more exact methods we take a little more time to interpolate for values that do not coincide exactly with the values given in the tables. In addition to this, we will describe some variations in the method of application, which are convenient at times.

FOURTH PROBLEM

We will repeat our first problem, working it out accurately this time. Span, 800 feet. Wire, 0000 stranded, hard-drawn

copper. Heavy loading. Required to know the sag at zero temperature under maximum conditions, and with unloaded wire at 60 degrees.

As before, we find from the wire tables the value of $\frac{w}{p}$ for this wire to be 0.0003282. Then $\frac{sw}{p} = \frac{s}{y} = 0.0003282 \times 800 = 0.26256$. For the sag corresponding to this value, we interpolate between the values for 0.262 and 0.263. The difference in the sag factor ($= 0.0001289$) $\times$ 0.56 = 0.0000722. Adding this to the sag factor for $\frac{s}{y} = 0.262$, we have $0.0330845 + 0.0000722 = 0.0331567$. This multiplied by the span (800 feet) gives 26.52536 feet as the sag under maximum conditions at zero.

Interpolating for the length factor between 0.262 and 0.263, we have $1.0029129 + (0.56 \times 0.0000227) = 1.0029256$.

To get the stretch of the wire we will interpolate the value in the "Stretch $\times \frac{s}{y}$" column, which gives us 0.9971100. Dividing this by 0.26256 we get 3.7976462 as the stretch factor. The elastic factor for this wire, from the wire tables, is 0.0000007572. The stretch, then, is $3.7976462 \times 0.0000007572 \times 800 = 0.0023005$.

Unstressed length of wire at zero will be 1.0029256 — 0.0023005 =	1.0006251
Unstressed length at 60 degrees is 1.0006251 $\times$ (1 + 0.0000096 $\times$ 60) =	1.0012015
First multiplication. 4 $\times$ 0.00023808 (see previous calculation)	0.0009523
First sum	1.0021538
Second multiplication. 0.3 $\times$ 0.00023808	0.0000714
Second sum	1.0022252

Third multiplication (completing factor for $\frac{s}{y} = 0.230$)

0.0382×0.00023808 ....0.0000091

Final sum 1.0022343

This shows that the value of $\frac{s}{y}$ is between 0.229 and 0.230. In working by the method, which we will call our "standard method," the third multiplication and sum would not have been necessary, as a little mental calculation would have been sufficient to show that the value would come between 0.229 and 0.230; we have done this work, however, to enable us to apply another method, without recalculation.

First we will explain what we will call our "standard method," since it is the easiest for a beginner in this system to grasp, and for some time the easiest to apply. The writer now usually uses another method which is explained after this one.

STANDARD METHOD

Having determined the two values of $\frac{s}{y}$, between which the true value will come, we determine the unstressed length for these two values, and interpolate for the value of the unstressed length of the wire.

In this case we will determine the unstressed length for $\frac{s}{y} = 0.229$ and for 0.230:

Length factor for 0.230 ....1.0022353
Stretch of wire$=4.3381980 \times 0.00023808$ 0.0010328

Unstressed length for $\frac{s}{y} = 0.230$ is equal to the difference 1.0012025
Length of factor for 0.229 ....1.0022157
Stretch of wire $= 4.3572264 \times 0.00023808$ 0.0010374

Unstressed length = difference 1.0011783

Interpolation:

Unstressed length for 0.230 (1.0012025) — length for 0.229 (1.0011783) = 0.0000242.

Unstressed length at 60 degrees (1.0012015) — length for 0.229 (1.0011783) = 0.0000232.
Dividing 0.0000232 by 0.0000242 we have 0.959. The true value of $\frac{s}{y}$ is 0.229959.

Sag factor is factor for 0.230 (0.0289752) — (0.041 $\times$ 0.0001280) = 0.0289700.

Sag at 60 degrees is 800 feet $\times$ 0.0289700 = 23.1760.

ALTERNATIVE METHOD

We have seen that by multiplying the stretch factor of the wire by the span, and that by the stretch factor corresponding to $\frac{s}{y} = 0.230$, we get a length factor of 1.0022343, which is 0.0000010 less than the length factor corresponding to the stretch factor we have assumed. This length factor is 0.0000186 longer than the length factor corresponding to $\frac{s}{y} = 0.229$, but, since the stretch factor for 0.229 is 0.0190284 greater than the stretch factor for 0.230, we would have had a length factor of 1.0022343 + (0.00023808 $\times$ 0.0190284) = 1.0022388, if we had used the stretch factor for 0.229. This is 0.0000231 more than the length factor for 0.229, so we see that the virtual change in length factor at this point in the tables, and for this wire, is 0.0000231 + 0.0000010 = 0.0000241.

This gives us this rule for getting the virtual change in length factor corresponding to any place in the table. Multiply the difference in the stretch factor between the two values of $\frac{s}{y}$ by the elastic factor of the wire, times the span $\left\{ = \frac{ws}{ae} \right\}$ and add the result to the difference in the corresponding length factors. In the

case under consideration, we have the elastic factor of the wire multiplied by the span $\left\{ = \frac{ws}{ae} \right\}$ equal to 0.00023808. The difference in stretch factor is 0.0190284, and the difference in the length factor is 0.0000196. $(0.00023808 \times 0.0190284) + 0.000196 = 0.0000241$.

As we found the length factor to be 0.0000010 too short, when we used the stretch factor corresponding to 0.230, so the actual value of $\frac{s}{y}$ will be $\frac{10}{241}$, or 0.0415 of 0.001 less than 0.230, or 0.2299585. This, by interpolation, gives us a sag factor of 0.0289699, which multiplied by the span gives a sag of 25.1759.

There is a discrepancy of 0.0001 in the results by this method and by the standard method, but it would require a micrometer to measure it. The standard method is the more accurate of the two methods, if one is desirous of obtaining as near absolute accuracy as possible.

The last method reduces to the following. Add to the unstressed length of the wire, the product of the elastic factor of the wire multiplied by the span $\left\{ = \frac{ws}{ae} \right\}$, and that by the stretch factor (from the table) which will come nearest to giving the corresponding length factor. Add the product to the difference in length factor to find the virtual difference in the length factor for that interval. Take the difference between the length factor obtained in the first operation, and the length factor corresponding to the stretch factor used. Divide this difference by this virtual difference in the length factor. Add (or subtract, as occasion may require) this fraction of 0.001 to (or from) the value of $\frac{s}{y}$ corresponding to the stretch factor used, and by interpolation determine the actual sag factor. This multiplied by the span will give the sag.

Either of these methods is very accurate except on the very low values of $\frac{s}{y}$. Even here, for practical work, they will give

values far more accurate than any work can be done in the field; in fact, even here, it would require a micrometer to measure the error. For the first three pages of the table, the writer would recommend the use of the standard method in preference to the last method explained.

If extreme accuracy is desired on very short spans, the following method can be used, and for those who are familiar with Horner's method of solving higher power equations, this method is often shorter than either of the other methods.

This method is applied by solving the following equation:

Let L' = unstressed length of wire.

C = elastic factor of wire multiplied by span $\left\{\frac{ws}{ac}\right\}$.

x = value of $\frac{s}{y}$ to be determined.

$$x^3 + Cx^2 + 24\,(1 - L')\,x - 24C = 0.$$

The value of x, as found by this equation, will be the value of $\frac{s}{y}$ which we use to determine the sag factor. This result will be accurate to six decimals for all values on the first page of the sag calculating tables, and to five decimal places for nearly all the values on the second page. For all values on the first page, the omission of the second term in the equation, Cx^2, will make no appreciable change in the result.

This equation is a simplification of the real formula for finding the sag directly from the unstressed length and the elastic factor of the wire. The real formula is too complicated for practical application and will not be discussed here as it would be of only academic interest.

Further application of this formula can be made in the following manner:

Solve the problem according to the equation given. If the value of $\frac{s}{y}$ thus found falls in the third page, or above, of the table, then square the value of x (to the nearest 0.001) so found, and divide by 24. Subtract this result from the length factor

corresponding to the value of $\dfrac{s}{y} = x$, and use the remainder in place of 1 in the term $(1 - L')$. From the corrected equation find x. This will give good results for the first five pages of the table, and with a second similar correction will give accurate results into the seventh page. It will be noted that when the unstressed length of the wire is less than unity, the third term of the equation is a plus quantity, but when the unstressed length is more than unity, the third term is a minus quantity.

One short illustration will be given to show the operation of this method before closing this part of our discussion.

Span, 120 feet. Wire, 0 copper-clad steel, stranded. Heavy loading. Required to know the sag at 60 degrees with unloaded wire.

Without giving here the calculations, which would only be a repetition of the methods discussed above, we determine the unstressed length of wire at 60 degrees to be 0.9980347. The elastic factor of the wire multiplied by the span is 0.000022896.

Applying the formula, $L' = 0.9980347$. $(1-L') = 0.0019653$. $C = 0.000022896$.

$x^3 + Cx^2 + 24\,(1-L')\,x - 24C = x^3 + 0.0000229x^2 + 0.0471672x - 0.000549504 = 0$.

$$x = 0.0116168 = \frac{s}{y}.$$

By interpolation, we find the sag factor to be 0.0014521, which multiplied by the span (120 feet) gives us a sag of 0.1743 feet.

Solving this problem by the "standard method," gives us a sag of 0.1745 feet, showing that the error of the "standard method" even on this short span is negligible.

All these calculations are based on the supposition that the supports at each end of the span are on the same level. In actual practice, this is rarely the case, except where the supports are purposely so designed as to be on a level. Among the hundreds of spans which the writer has designed, he can recollect only one case where the supports have been on the same level, except in cases such as we have mentioned.

Much has been written on the subject of determining the sag for spans where the supports are not on the same level. The writer knows of no practical, accurate method. The method here given is one which the writer has devised, which he believes to be the easiest to apply of all the methods which he has investigated, and which he considers to be the most accurate for practical application.

Advantage is taken of a property of the common parabola, which is very little mentioned in text-books. In fact, the writer had been using this method for several years, before he saw this peculiarity mentioned in any book.

This property is illustrated in Fig. 19. Stated mathematically,

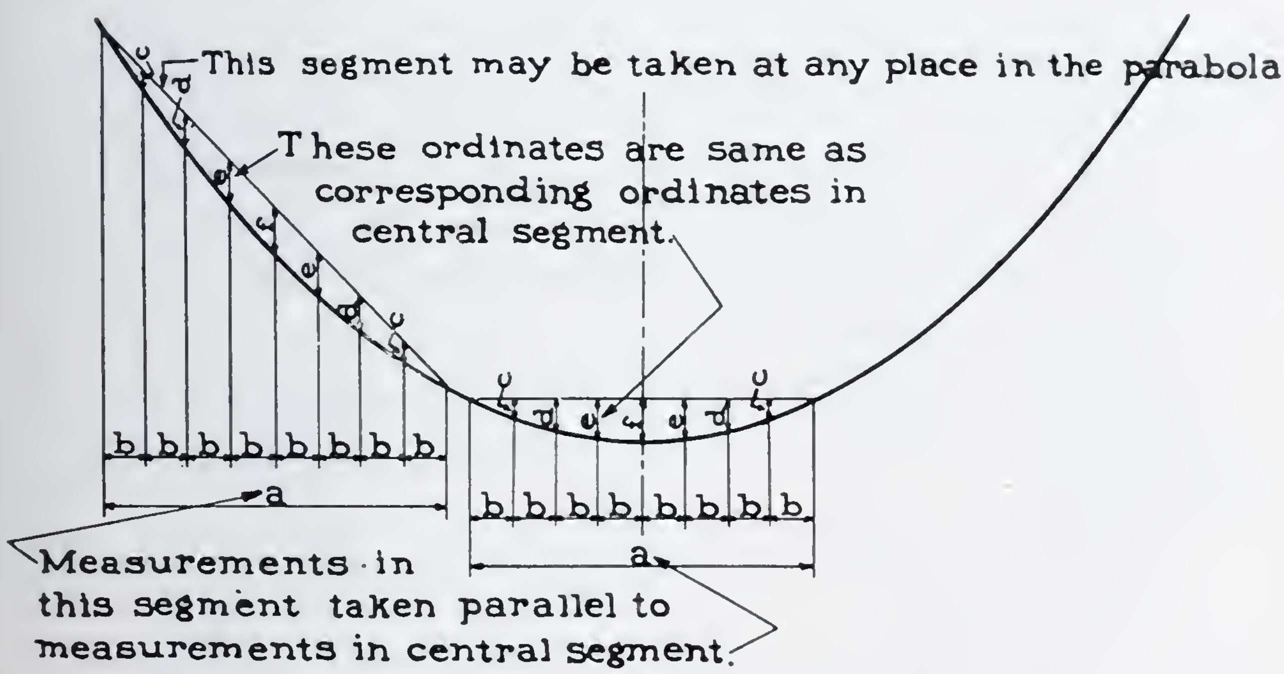

Fig. 19. Method of Calculating Sag in Hillside Spans.

this property is described thus: If through any point in a parabola, we pass a line parallel to the principal axis, and a tangent, then the equation of the parabola, referred to these lines as oblique axes, will be the same as the equation of the parabola when referred to the principal axis and the tangent at the vertex, as rectangular axes. This shows that the common parabola is a curve every part of which is simply a distortion of every other part.

If the wire were to hang in a true parabola, then the method of obtaining the true sag, by taking the middle ordinate measured

vertically from the middle of the chord to the arc of the parabola (as illustrated in Fig. 20) would be accurate without any correc-

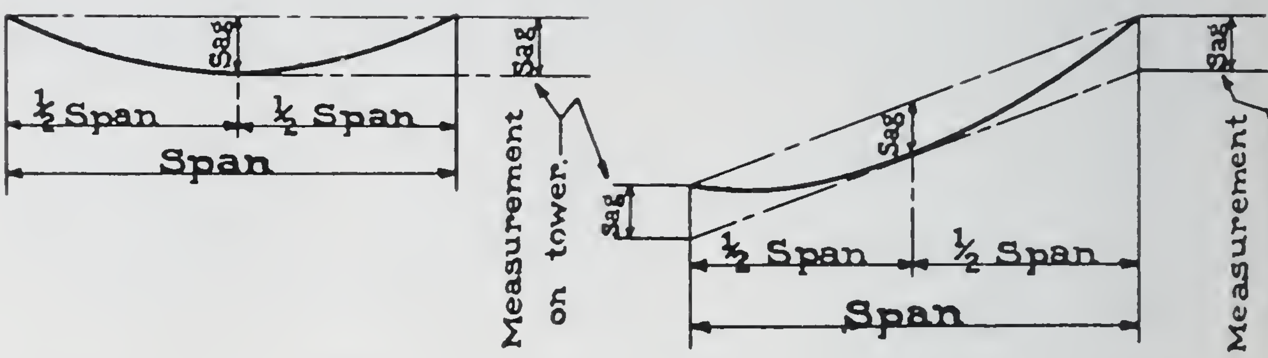

Fig. 20. Method of Calculating Sag in Hillside Spans.

tion. In other words, all that is necessary is to measure the amount of sag required for the span measured horizontally the same as if it were a level span; this measurement to be taken vertically from the point of support on each tower, and establish a line of sight between these points. Then allow the wire to sag till it coincides with the line of sight.

Since our figures are based on the assumption that the curve is a catenary, a correction must be made in the sag to atone for this differencee.

Let E = difference in elevation between points of support.

S = span.

H = sag for level span, as calculated from tables.

H' = sag as corrected for sloping span.

W = weight of wire per foot, under maximum conditions of loading.

P = maximum allowed tension in wire.

The value of H used in these formulæ should be the value formula:

$$H' = H\left[1 + \frac{\frac{1}{2}\left(\frac{E^2}{4H} + E\right)}{\frac{P}{W} - \frac{1}{2}\left(\frac{E^2}{4H} + E\right)}\right].$$

Or, in other words, the per cent. we add to the sag as figured for a level span, to find the corrected sag for the sloping span is:

$$\frac{50\left(\frac{E^2}{4H}+E\right)}{\frac{P}{W}-\frac{1}{2}\left(\frac{E^2}{4H}+E\right)}.$$

The value of H used in these formulæ should be the value of the sag under maximum conditions of loading.

The man in charge of stringing the wire should be furnished with a chart showing the sag required for any span at any temperature; and, with this chart, a table giving the span between each pair of towers, the difference in elevation, the per cent. to be added to the sag, and the type of insulators to be used.

The table would read something like the following example, taken from a table for a transmission line.

Tower No.	Span in feet	Difference in elevation in feet	Per cent. added to sag	Type of insulator
1024	759.90	+113.00	4.36	strain
1025	850.00	+ 53.00	1.34	suspension
1026	626.00	— 42.50	1.22	suspension
1027	516.00	— 23.50	0.62	combination
1028	533.00	— 84.50	4.06	suspension
1029	719.50	— 76.50	2.53	suspension
1030	1100.50	+114.50	3.19	strain
1031				suspension

There is another method, slightly less accurate but more easily applied, and close enough for practical purposes, and as accurate as, if not more accurate than, any other method the writer has seen published. This method is applied as follows:

Find the sag for the span as measured horizontally. Next find the sag for a span of a length equal to the actual distance (measured on the slope) between the points of support. This last value for the sag will be the greater, since the span considered is longer.

To the larger of these two sags add the difference between the two, and use the sum as the value of the sag, measured vertically.

The table given the man in charge of stringing the wire would read as follows:

Tower No.	Span in feet	Difference in elevation in feet	Slope span in feet	Type of insulator
1024				suspension
	719.5	— 76.5	723.6	
1025				strain
	533.0	— 84.5	539.7	
1026				suspension
	516.0	— 23.5	516.5	
1027				suspension
	626.0	— 42.5	627.4	
1028				combination
	850.0	+ 53.0	851.6	
1029				suspension
	759.9	+113.0	768.2	
1030				suspension
	1100.5	+114.5	1106.4	
1131				strain

As an example, take the span between towers No. 1030 and No. 1031. Suppose the temperature of the wire to be 60 degrees at the time it is strung. The chart that was used for stringing the line, from which this portion of the table is copied, gives the required sag at 60 degrees, for a span of 1100.5 feet, as 53.5 feet; while for a span of 1106.4 feet it gives 54.2 feet. The difference between these two values is 0.7 of a foot. This added to 54.2 feet gives 54.9 feet as the sag, measured vertically, which would be used in this case.

Sometimes it is necesary to know the elevation of the low point of the wire. This is necessary in getting permits for crossing over rivers, which are under control of the United States government, sometimes for railway crossings, and sometimes where the nature of the ground is such that sagging by the method already described would be difficult or impossible.

In this case, a resort to a parabolic formula will give results close enough to true values for all practical purposes, if the correction in the sag, to allow for the difference between the catenary and the parabola, has been made.

Letting D equal the elevation of the lower of the two supports, we find the elevation of the low point of the wire, which we will call D', by the following formula:

$$D' = D - \frac{1}{H'}\left(H' - \frac{E}{4}\right)^2.$$

The distance from the lower point of support to the low point of the wire, horizontally, which we will call B, can be found as follows:

$$B = \frac{S}{2H'}\left(H' - \frac{E}{4}\right).$$

The first of these two formulæ gives the elevation within a small fraction of one per cent. in nearly all cases, but the second will vary from the true value by as much as two per cent. and sometimes more. As the curve is a long one, and the tangent remains very close to the curve for a considerable distance on either side of the point of tangency, the error in the second formula is of no serious import, especially as the horizontal position of the low point changes with each change of temperature or condition of loading.

The value of H', used in these last two formulæ, should be the sag as calculated for the temperature at which the elevation is to be determined, to which the percentage of correction as determined by the formula, previously given, has been added. For instance, if the sag, under conditions of maximum loading, is 105 feet, and, at the temperature under consideration, is 100 feet, then we use 105 feet as the value of H to determine the percentage of correction to be added, which let us assume, amounts to five per cent. We would then use 100 feet + five per cent. or 105 feet for the value of H' for the temperature in the case under consideration.

The writer does not claim a high degree of accuracy for this method of determining the sag of wire on hillside spans. The catenary is such a complicated curve that it is hardly probable that a formula can be devised which would give accurate results and at the same time be simple enough to be workable.

The method here presented will give as accurate results, the writer believes, as any method yet published. In fact, he knows it to be more accurate than several that have been published, and it is workable, which is more than can be said of a number of methods which he has seen in print.

One more word as to the methods of applying this method in the field. It often happens that the sag is so great that it can not be measured on the tower, the line of sight, parallel to the line joining the two points of support, in some cases striking the hillside far below the tower. In these cases, the man in charge

pegs down the hill with his transit and leveling rod, till his telescope is on the line of sight. He then tilts the telescope to the angle of inclination of the line of sight, and the sagging of the wire proceeds. For this purpose, the field man should have his "Searles"* or other convenient handbook, always with him.

As to the relative economy of this method, compared with the common method of calculating the low point in the wire and sagging the wire to that elevation, the method we have described has proved so much more economical both in time and money that there is no comparison.

One more method of determining the sag might be mentioned; that is, by a dynamometer. The only advantage in this method is that it helps to keep the dynamometer manufacturers and salesmen employed. Aside from this, the less said about that method the better, and the sooner it is forgotten the better off the construction companies will be.

In closing, we would speak of the type of sag chart that should be sent to the field to guide the men in sagging the wires. On any line, only one kind of wire is used except in a few special cases; and the writer believes the best kind of chart is one made out for the kind of wire being used on the line being constructed, and for that kind of wire only. The writer's practice is to plot the curves for the sag of the wire (at each 10 degrees of temperature) on cross-section cloth, using the horizontal measurements to represent the span (usually at 50 feet to the inch) and the vertical measurements to represent the sags (usually at two feet to the inch). To determine the sag, it is only necessary to know the span and the temperature. Looking at the chart, one follows the line representing the span till it crosses the curve. Then, following the line representing the sag, to where the sag is marked, complete the operation without going to another chart to find the variation for temperature, as is done in so many systems.

A sample of the type of chart used by the writer is appended to this paper (see Fig. 21). This will illustrate it so that we do not believe there is any further need of explanation, so with this

*Field Engineering, by W. H. Searles, Ed. 17, 1915. Wiley, New York.

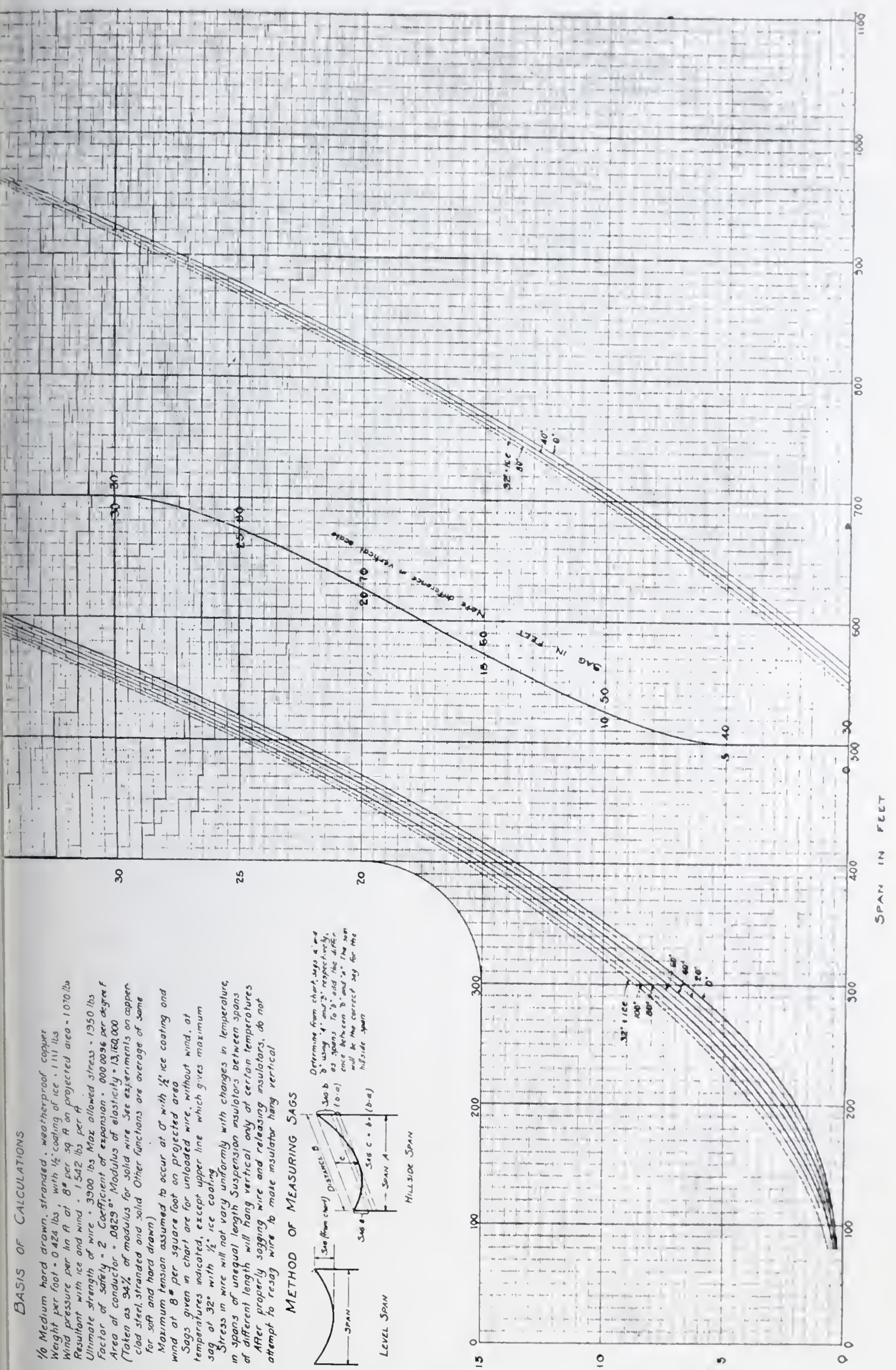

Fig. 21. Standard Sag Chart.

and the tables we will close this paper.

The writer wishes to express his thanks to Mr. C. W. Bonnell, agent for the Marchant Calculating Machine, for his kindness in loaning one of these machines to the writer, thus greatly assisting in the work of calculation. Also, thanks are due to Mr. P. A. Young for his assistance in checking results, and Mr. H. E. Warren for his assistance in picking out the logarithms for the tables.

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y}=\frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.000	0.0000000		1.00000000		Infinite		1.0000000
0.001	0.0001250	1250	1.00000004	0004	999.9999427	Infinite	0.9999999
0.002	0.0002500	1250	1.00000017	0013	499.9999167	500.0000260	0.9999998
0.003	0.0003750	1250	1.00000038	0021	333.3332092	166.6667075	0.9999996
0.004	0.0005000	1250	1.00000067	0029	249.9998333	83.3333759	0.9999993
0.005	0.0006250	1250	1.00000104	0037	199.9997915	50.0000418	0.9999990
0.006	0.0007500	1250	1.0000015	0046	166.6664167	33.3333748	0.9999985
0.007	0.0008750	1250	1.0000020	005	142.8568512	23.8095655	0.9999980
0.008	0.0010000	1250	1.0000027	007	124.9996688	17.8571824	0.9999973
0.009	0.0011250	1250	1.0000034	007	111.1107338	13.8889350	0.9999966
0.010	0.0012500	1250	1.0000042	008	99.9995850	11.1111488	0.9999958
0.011	0.0013750	1250	1.0000050	008	90.9086325	9.0909525	0.9999950
0.012	0.0015000	1250	1.0000060	010	83.3328333	7.5757992	0.9999940
0.013	0.0016250	1250	1.0000070	010	76.9225352	6.4102981	0.9999930
0.014	0.0017500	1250	1.0000082	012	71.4279893	5.4945459	0.9999918
0.015	0.0018750	1250	1.0000094	012	66.6660417	4.7619476	0.9999906
0.016	0.0020000	1250	1.0000107	013	62.4993344	4.1667073	0.9999893
0.017	0.0021250	1250	1.0000120	013	58.8228211	3.6765133	0.9999880
0.018	0.0022501	1251	1.0000135	015	55.5548055	3.2680156	0.9999865
0.019	0.0023751	1250	1.0000150	015	52.6307872	2.9240183	0.9999850
0.020	0.0025001	1250	1.0000167	017	49.9991672	2.6316200	0.9999833
0.021	0.0026251	1250	1.0000184	017	47.6181726	2.3809946	0.9999816
0.022	0.0027502	1251	1.0000202	018	45.4536294	2.1645432	0.9999798
0.023	0.0028752	1250	1.0000220	018	43.4773024	1.9763270	0.9999780
0.024	0.0030002	1250	1.0000240	020	41.6656666	1.8116358	0.9999760
0.025	0.0031253	1251	1.0000260	020	39.9989582	1.6667084	0.9999740
0.026	0.0032503	1250	1.0000282	022	38.4604556	1.5385026	0.9999718
0.027	0.0033754	1251	1.0000304	022	37.0359118	1.4245438	0.9999696
0.028	0.0035004	1250	1.0000327	023	35.7131194	1.3227924	0.9999673
0.029	0.0036255	1251	1.0000350	023	34.4815500	1.2315694	0.9999650
0.030	0.0037505	1250	1.0000375	025	33.3320831	1.1494669	0.9999625
0.031	0.0038756	1251	1.0000401	026	32.2567725	1.0753106	0.9999599
0.032	0.0040006	1250	1.0000427	026	31.2486669	1.0081056	0.9999573
0.033	0.0041257	1251	1.0000454	027	30.3016550	0.9470119	0.9999546
0.034	0.0042508	1251	1.0000482	028	29.4103481	0.8913069	0.9999518
0.035	0.0043759	1251	1.0000510	028	28.5699706	0.8403775	0.9999490
0.036	0.0045010	1251	1.0000540	030	27.7762773	0.7936933	0.9999460
0.037	0.0046261	1251	1.0000570	030	27.0254856	0.7507917	0.9999430
0.038	0.0047511	1250	1.0000602	032	26.3142060	0.7112796	0.9999398
0.039	0.0048762	1251	1.0000634	032	25.6394004	0.6748056	0.9999366
0.040	0.0050012	1250	1.0000667	033	24.9983332	0.6410672	0.9999333
0.041	0.0051263	1251	1.0000701	034	24.3885356	0.6097976	0.9999299
0.042	0.0052514	1251	1.0000735	034	23.8077732	0.5807624	0.9999264
0.043	0.0053765	1251	1.0000771	036	23.2540222	0.5537510	0.9999229
0.044	0.0055016	1251	1.0000807	036	22.7254390	0.5285832	0.9999193
0.045	0.0056267	1251	1.0000844	037	22.2203467	0.5050923	0.9999156
0.046	0.0057518	1251	1.0000882	038	21.7372132	0.4831335	0.9999118
0.047	0.0058769	1251	1.0000921	039	21.2746371	0.4625761	0.9999079
0.048	0.0060020	1251	1.0000960	039	20.8313323	0.4433048	0.9999040
0.049	0.0061271	1251	1.0001001	041	20.4061211	0.4252112	0.9998999
0.050	0.0062523	1252	1.0001042	041	19.9979158	0.4082053	0.9998958

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y}=\frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.050	0.0062523	1251	1.0001042	042	19.9979158	0.3921986	0.9998958
0.051	0.0063774	1251	1.0001084	043	19.6057172	0.3771155	0.9998916
0.052	0.0065025	1251	1.0001127	044	19.2286017	0.3628863	0.9998873
0.053	0.0066276	1252	1.0001171	045	18.8657154	0.3494474	0.9998829
0.054	0.0067528	1252	1.0001216	046	18.5162680	0.3367416	0.9998785
0.055	0.0068780	1252	1.0001262	046	18.1795264	0.3247172	0.9998739
0.056	0.0070032	1252	1.0001308	047	17.8548092	0.3133252	0.9998693
0.057	0.0071284	1252	1.0001355	048	17.5414840	0.3025220	0.9998646
0.058	0.0072536	1252	1.0001403	049	17.2389620	0.2922684	0.9998598
0.059	0.0073788	1252	1.0001452	049	16.9466936	0.2825281	0.9998549
0.060	0.0075040	1252	1.0001501	051	16.6641655	0.2732653	0.9998499
0.061	0.0076292	1252	1.0001552	051	16.3909002	0.2644523	0.9998449
0.062	0.0077544	1252	1.0001603	053	16.1264479	0.2560575	0.9998398
0.063	0.0078796	1252	1.0001656	053	15.8703904	0.2480576	0.9998346
0.064	0.0080048	1252	1.0001709	054	15.6223328	0.2404263	0.9998293
0.065	0.0081300	1252	1.0001763	054	15.3819065	0.2331425	0.9998239
0.066	0.0082552	1252	1.0001817	056	15.1487640	0.2261833	0.9998184
0.067	0.0083804	1253	1.0001873	056	14.9225807	0.2195328	0.9998129
0.068	0.0085057	1253	1.0001929	057	14.7030479	0.2131704	0.9998073
0.069	0.0086310	1253	1.0001986	058	14.4898775	0.2070813	0.9998015
0.070	0.0087563	1252	1.0002044	059	14.2827962	0.2012489	0.9997957
0.071	0.0088815	1253	1.0002103	060	14.0815473	0.1956597	0.9997899
0.072	0.0090068	1253	1.0002163	061	13.8858876	0.1903002	0.9997839
0.073	0.0091321	1253	1.0002224	061	13.6955874	0.1851587	0.9997779
0.074	0.0092574	1253	1.0002285	062	13.5104287	0.1802221	0.9997717
0.075	0.0093827	1253	1.0002347	063	13.3302066	0.1754804	0.9997655
0.076	0.0095080	1253	1.0002410	064	13.1547262	0.1709234	0.9997592
0.077	0.0096333	1254	1.0002474	065	12.9838028	0.1665418	0.9997528
0.078	0.0097587	1253	1.0002539	066	12.8172610	0.1623264	0.9997464
0.079	0.0098840	1254	1.0002605	066	12.6549346	0.1582699	0.9997398
0.080	0.0100094	1253	1.0002671	067	12.4966647	0.1543629	0.9997332
0.081	0.0101347	1254	1.0002738	068	12.3423018	0.1505989	0.9997264
0.082	0.0102601	1253	1.0002806	069	12.1917029	0.1469709	0.9997196
0.083	0.0103854	1254	1.0002875	070	12.0447320	0.1434725	0.9997128
0.084	0.0105108	1254	1.0002945	071	11.9012595	0.1400976	0.9997058
0.085	0.0106362	1254	1.0003016	071	11.7611619	0.1368410	0.9996988
0.086	0.0107616	1254	1.0003087	073	11.6243209	0.1336954	0.9996916
0.087	0.0108870	1254	1.0003160	073	11.4906255	0.1306584	0.9996844
0.088	0.0110124	1255	1.0003233	074	11.3599671	0.1277231	0.9996771
0.089	0.0111379	1254	1.0003307	075	11.2322440	0.1248857	0.9996697
0.090	0.0112633	1254	1.0003382	076	11.1073583	0.1221417	0.9996622
0.091	0.0113887	1255	1.0003458	077	10.9852166	0.1194873	0.9996547
0.092	0.0115142	1255	1.0003535	077	10.8657293	0.1169190	0.9996471
0.093	0.0116397	1255	1.0003612	078	10.7488103	0.1144323	0.9996394
0.094	0.0117652	1255	1.0003690	079	10.6343780	0.1120236	0.9996315
0.095	0.0118907	1255	1.0003769	080	10.5223544	0.1096911	0.9996237
0.096	0.0120162	1255	1.0003849	081	10.4126633	0.1074300	0.9996157
0.097	0.0121417	1255	1.0003930	082	10.3052333	0.1052383	0.9996076
0.098	0.0122672	1255	1.0004012	083	10.1999950	0.1031135	0.9995995
0.099	0.0123927	1256	1.0004095	083	10.0968815	0.1010517	0.9995913
0.100	0.0125183		1.0004178		9.9958298		0.9995830

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.100	0.0125183		1.0004178		9.9958298		0.9995830
0.101	0.0126438	1255	1.0004262	084	9.8967782	0.0990516	0.9995746
0.102	0.0127694	1256	1.0004347	085	9.7996678	0.0971104	0.9995661
0.103	0.0128949	1255	1.0004433	086	9.7044417	0.0952261	0.9995575
0.104	0.0130205	1256	1.0004520	087	9.6110474	0.0933943	0.9995489
0.105	0.0131461	1256	1.0004608	088	9.5194305	0.0916169	0.9995402
0.106	0.0132717	1256	1.0004696	088	9.4295415	0.0898890	0.9995314
0.107	0.0133973	1256	1.0004785	089	9.3413317	0.0882098	0.9995225
0.108	0.0135230	1257	1.0004875	090	9.2547547	0.0865770	0.9995135
0.109	0.0136486	1256	1.0004966	091	9.1697651	0.0849896	0.9995044
0.110	0.0137743	1257	1.0005058	092	9.0863210	0.0834441	0.9994953
0.111	0.0139000	1257	1.0005151	093	9.0043793	0.0819417	0.9994861
0.112	0.0140257	1257	1.0005244	093	8.9238996	0.0804797	0.9994768
0.113	0.0141514	1257	1.0005339	095	8.8448442	0.0790554	0.9994674
0.114	0.0142771	1257	1.0005434	095	8.7671746	0.0776696	0.9994579
0.115	0.0144028	1257	1.0005530	096	8.6908548	0.0763198	0.9994483
0.116	0.0145286	1258	1.0005627	097	8.6158508	0.0750040	0.9994387
0.117	0.0146543	1257	1.0005725	098	8.5421273	0.0737235	0.9994289
0.118	0.0147801	1258	1.0005823	098	8.4696536	0.0724737	0.9994191
0.119	0.0149058	1257	1.0005923	100	8.3983966	0.0712570	0.9994092
0.120	0.0150316	1258	1.0006023	100	8.3283271	0.0700695	0.9993993
0.121	0.0151574	1258	1.0006124	101	8.2594149	0.0689122	0.9993892
0.122	0.0152832	1258	1.0006226	102	8.1916313	0.0677836	0.9993790
0.123	0.0154090	1258	1.0006329	103	8.1249496	0.0666817	0.9993688
0.124	0.0155349	1259	1.0006433	104	8.0593427	0.0656069	0.9993585
0.125	0.0156607	1258	1.0006538	105	7.9947840	0.0645587	0.9993480
0.126	0.0157866	1259	1.0006643	105	7.9312507	0.0635333	0.9993375
0.127	0.0159125	1259	1.0006749	106	7.8687157	0.0625350	0.9993269
0.128	0.0160384	1259	1.0006856	107	7.8071589	0.0615568	0.9993163
0.129	0.0161643	1259	1.0006964	108	7.7465550	0.0606039	0.9993056
0.130	0.0162902	1259	1.0007073	109	7.6868830	0.0596720	0.9992948
0.131	0.0164161	1259	1.0007183	110	7.6281214	0.0587616	0.9992839
0.132	0.0165421	1260	1.0007293	110	7.5702490	0.0578724	0.9992729
0.133	0.0166681	1260	1.0007405	112	7.5132466	0.0570024	0.9992618
0.134	0.0167941	1260	1.0007517	112	7.4570944	0.0561522	0.9992506
0.135	0.0169201	1260	1.0007630	113	7.4017733	0.0553211	0.9992394
0.136	0.0170461	1260	1.0007744	114	7.3472652	0.0545081	0.9992281
0.137	0.0171721	1260	1.0007859	115	7.2935526	0.0537126	0.9992167
0.138	0.0172982	1261	1.0007975	116	7.2406172	0.0529354	0.9992052
0.139	0.0174242	1260	1.0008092	117	7.1884432	0.0521740	0.9991936
0.140	0.0175503	1261	1.0008209	117	7.1370138	0.0514294	0.9991819
0.141	0.0176764	1261	1.0008327	118	7.0863128	0.0507010	0.9991701
0.142	0.0178025	1261	1.0008446	119	7.0363262	0.0499866	0.9991583
0.143	0.0179286	1261	1.0008566	120	6.9870378	0.0492884	0.9991464
0.144	0.0180548	1262	1.0008687	121	6.9384334	0.0486044	0.9991344
0.145	0.0181809	1261	1.0008809	122	6.8904986	0.0479348	0.9991223
0.146	0.0183071	1262	1.0008932	123	6.8432204	0.0472782	0.9991102
0.147	0.0184333	1262	1.0009056	124	6.7965844	0.0466360	0.9990979
0.148	0.0185595	1262	1.0009180	124	6.7505784	0.0460060	0.9990856
0.149	0.0186857	1262	1.0009305	125	6.7051893	0.0453891	0.9990732
0.150	0.0188119	1262	1.0009431	126	6.6604044	0.0447849	0.9990607

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.150	0.0188119	1262	1.0009431	127	6.6604044	0.0441918	0.9990607
0.151	0.0189381	1263	1.0009558	127	6.6162126	0.0436116	0.9990481
0.152	0.0190644	1263	1.0009685	128	6.5726010	0.0430415	0.9990354
0.153	0.0191907	1263	1.0009813	130	6.5295595	0.0424833	0.9990226
0.154	0.0193170	1263	1.0009943	131	6.4870762	0.0419352	0.9990097
0.155	0.0194433	1264	1.0010074	131	6.4451410	0.0413986	0.9989968
0.156	0.0195697	1263	1.0010205	132	6.4037424	0.0408716	0.9989838
0.157	0.0196960	1264	1.0010337	133	6.3628708	0.0403548	0.9989707
0.158	0.0198224	1264	1.0010470	134	6.3225160	0.0398476	0.9989575
0.159	0.0199488	1264	1.0010604	135	6.2826684	0.0393501	0.9989442
0.160	0.0200752	1264	1.0010739	136	6.2433183	0.0388616	0.9989309
0.161	0.0202016	1265	1.0010875	136	6.2044567	0.0383828	0.9989175
0.162	0.0203281	1264	1.0011011	137	6.1660739	0.0379122	0.9989040
0.163	0.0204545	1265	1.0011148	138	6.1281617	0.0374504	0.9988904
0.164	0.0205810	1265	1.0011286	139	6.0907113	0.0369969	0.9988767
0.165	0.0207075	1265	1.0011425	140	6.0537144	0.0365516	0.9988629
0.166	0.0208340	1265	1.0011565	141	6.0171628	0.0361143	0.9988490
0.167	0.0209605	1266	1.0011706	142	5.9810485	0.0356849	0.9988351
0.168	0.0210871	1266	1.0011848	143	5.9453636	0.0352631	0.9988211
0.169	0.0212137	1266	1.0011991	143	5.9101005	0.0348490	0.9988070
0.170	0.0213403	1266	1.0012134	144	5.8752515	0.0344417	0.9987928
0.171	0.0214669	1266	1.0012278	145	5.8408098	0.0340418	0.9987785
0.172	0.0215935	1266	1.0012423	146	5.8067680	0.0336486	0.9987641
0.173	0.0217201	1267	1.0012569	147	5.7731194	0.0332624	0.9987497
0.174	0.0218468	1267	1.0012716	148	5.7398570	0.0328826	0.9987351
0.175	0.0219735	1267	1.0012864	148	5.7069744	0.0325097	0.9987205
0.176	0.0221002	1267	1.0013012	150	5.6744647	0.0321422	0.9987058
0.177	0.0222269	1268	1.0013162	150	5.6423225	0.0317825	0.9986910
0.178	0.0223537	1268	1.0013312	152	5.6105400	0.0314272	0.9986761
0.179	0.0224805	1268	1.0013464	152	5.5791128	0.0310787	0.9986611
0.180	0.0226073	1268	1.0013616	153	5.5480341	0.0307357	0.9986461
0.181	0.0227341	1269	1.0013769	154	5.5172984	0.0303984	0.9986310
0.182	0.0228610	1268	1.0013923	155	5.4869000	0.0300666	0.9986158
0.183	0.0229878	1269	1.0014078	156	5.4568334	0.0297402	0.9986005
0.184	0.0231147	1269	1.0014234	157	5.4270932	0.0294191	0.9985851
0.185	0.0232416	1269	1.0014391	157	5.3976741	0.0291035	0.9985697
0.186	0.0233685	1269	1.0014548	158	5.3685706	0.0287926	0.9985541
0.187	0.0234954	1269	1.0014706	159	5.3397780	0.0284868	0.9985385
0.188	0.0236223	1270	1.0014865	160	5.3112912	0.0281857	0.9985227
0.189	0.0237493	1270	1.0015025	161	5.2831055	0.0278895	0.9985069
0.190	0.0238763	1270	1.0015186	162	5.2552160	0.0275978	0.9984910
0.191	0.0240033	1271	1.0015348	163	5.2276182	0.0273107	0.9984751
0.192	0.0241304	1270	1.0015511	164	5.2003075	0.0270282	0.9984590
0.193	0.0242574	1271	1.0015675	164	5.1732793	0.0267502	0.9984429
0.194	0.0243845	1271	1.0015839	165	5.1465291	0.0264763	0.9984266
0.195	0.0245116	1272	1.0016004	166	5.1200528	0.0262064	0.9984103
0.196	0.0246388	1271	1.0016170	167	5.0938464	0.0259408	0.9983939
0.197	0.0247659	1272	1.0016337	168	5.0679056	0.0256792	0.9983774
0.198	0.0248931	1272	1.0016505	169	5.0422264	0.0254219	0.9983608
0.199	0.0250203	1272	1.0016674	170	5.0168045	0.0251673	0.9983441
0.200	0.0251475		1.0016844		4.9916372		0.9983274

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$= \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
.200	0.0251475		1.0016844		4.9916372		0.9983274
.201	0.0252747	1272	1.0017015	171	4.9667196	0.0249176	0.9983106
.202	0.0254020	1273	1.0017186	171	4.9420481	0.0246715	0.9982937
.203	0.0255293	1273	1.0017359	173	4.9176193	0.0244288	0.9982767
.204	0.0256566	1273	1.0017532	173	4.8934296	0.0241897	0.9982596
.205	0.0257839	1273	1.0017707	175	4.8694756	0.0239540	0.9982424
.206	0.0259113	1274	1.0017882	175	4.8457534	0.0237222	0.9982252
.207	0.0260387	1274	1.0018058	176	4.8222604	0.0234930	0.9982079
.208	0.0261661	1274	1.0018235	177	4.7989926	0.0232678	0.9981905
.209	0.0262935	1274	1.0018413	178	4.7759473	0.0230453	0.9981729
.210	0.0264210	1275	1.0018591	178	4.7531207	0.0228266	0.9981553
.211	0.0265485	1275	1.0018771	180	4.7305103	0.0226104	0.9981376
.212	0.0266760	1275	1.0018951	180	4.7081127	0.0223976	0.9981199
.213	0.0268035	1275	1.0019133	182	4.6859252	0.0221875	0.9981020
.214	0.0269311	1276	1.0019315	182	4.6639444	0.0219808	0.9980841
.215	0.0270586	1275	1.0019498	183	4.6421679	0.0217765	0.9980661
.216	0.0271862	1276	1.0019682	184	4.6205925	0.0215754	0.9980480
.217	0.0273138	1276	1.0019867	185	4.5992156	0.0213769	0.9980298
.218	0.0274415	1277	1.0020053	186	4.5780344	0.0211812	0.9980115
.219	0.0275692	1277	1.0020240	187	4.5570464	0.0209880	0.9979931
.220	0.0276969	1277	1.0020427	187	4.5362486	0.0207978	0.9979747
.221	0.0278246	1277	1.0020616	189	4.5156388	0.0206098	0.9979561
.222	0.0279523	1277	1.0020805	189	4.4952141	0.0204247	0.9979375
.223	0.0280801	1278	1.0020996	191	4.4749725	0.0202416	0.9979188
.224	0.0282079	1278	1.0021187	191	4.4549110	0.0200615	0.9979001
.225	0.0283357	1278	1.0021379	192	4.4350275	0.0198835	0.9978812
.226	0.0284635	1278	1.0021572	193	4.4153195	0.0197080	0.9978622
.227	0.0285914	1279	1.0021766	194	4.3957849	0.0195346	0.9978431
.228	0.0287193	1279	1.0021961	195	4.3764212	0.0193637	0.9978240
.229	0.0288472	1279	1.0022157	196	4.3572264	0.0191948	0.9978048
.230	0.0289752	1280	1.0022353	196	4.3381980	0.0190284	0.9977855
.231	0.0291032	1280	1.0022551	198	4.3193339	0.0188641	0.9977661
.232	0.0292312	1280	1.0022749	198	4.3006322	0.0187017	0.9977466
.233	0.0293592	1280	1.0022949	200	4.2820906	0.0185416	0.9977270
.234	0.0294873	1281	1.0023149	200	4.2637070	0.0183836	0.9977074
.235	0.0296154	1281	1.0023351	202	4.2454798	0.0182272	0.9976876
.236	0.0297435	1281	1.0023553	202	4.2274063	0.0180735	0.9976678
.237	0.0298716	1281	1.0023756	203	4.2094853	0.0179210	0.9976479
.238	0.0299998	1282	1.0023960	204	4.1917138	0.0177715	0.9976279
.239	0.0301280	1282	1.0024165	205	4.1740918	0.0176220	0.9976079
.240	0.0302563	1283	1.0024370	205	4.1566159	0.0174759	0.9975878
.241	0.0303845	1282	1.0024577	207	4.1392843	0.0173316	0.9975675
.242	0.0305128	1283	1.0024784	207	4.1220958	0.0171885	0.9975472
.243	0.0306411	1283	1.0024993	209	4.1050484	0.0170474	0.9975267
.244	0.0307694	1283	1.0025202	209	4.0881403	0.0169081	0.9975062
.245	0.0308978	1284	1.0025413	211	4.0713701	0.0167702	0.9974856
.246	0.0310262	1284	1.0025624	211	4.0547358	0.0166343	0.9974650
.247	0.0311546	1284	1.0025836	212	4.0382357	0.0165001	0.9974442
.248	0.0312831	1285	1.0026049	213	4.0218684	0.0163673	0.9974234
.249	0.0314116	1285	1.0026263	214	4.0056321	0.0162363	0.9974024
.250	0.0315401	1285	1.0026478	215	3.9895256	0.0161065	0.9973814

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.250	0.0315401		1.0026478		3.9895256		0.9973814
0.251	0.0316686	1285	1.0026694	216	3.9735470	0.0159786	0.9973603
0.252	0.0317972	1286	1.0026911	217	3.9576948	0.0158522	0.9973391
0.253	0.0319258	1286	1.0027129	218	3.9419677	0.0157271	0.9973178
0.254	0.0320544	1286	1.0027347	218	3.9263640	0.0156037	0.9972965
0.255	0.0321830	1286	1.0027567	220	3.9108824	0.0154816	0.9972750
0.256	0.0323117	1287	1.0027787	220	3.8955214	0.0153610	0.9972535
0.257	0.0324404	1287	1.0028009	222	3.8802796	0.0152418	0.9972318
0.258	0.0325692	1288	1.0028231	222	3.8651555	0.0151241	0.9972101
0.259	0.0326980	1288	1.0028454	223	3.8501479	0.0150076	0.9971883
0.260	0.0328268	1288	1.0028678	224	3.8352555	0.0148924	0.9971664
0.261	0.0329556	1288	1.0028903	225	3.8204768	0.0147787	0.9971444
0.262	0.0330845	1289	1.0029129	226	3.8058106	0.0146662	0.9971224
0.263	0.0332134	1289	1.0029356	227	3.7912556	0.0145550	0.9971002
0.264	0.0333423	1289	1.0029584	228	3.7768108	0.0144448	0.9970780
0.265	0.0334712	1289	1.0029813	229	3.7624744	0.0143364	0.9970557
0.266	0.0336002	1290	1.0030043	230	3.7482455	0.0142289	0.9970333
0.267	0.0337292	1290	1.0030274	231	3.7341230	0.0141225	0.9970108
0.268	0.0338583	1291	1.0030505	231	3.7201054	0.0140176	0.9969882
0.269	0.0339874	1291	1.0030737	232	3.7061916	0.0139138	0.9969655
0.270	0.0341165	1291	1.0030971	234	3.6923808	0.0138108	0.9969428
0.271	0.0342456	1291	1.0031206	235	3.6786717	0.0137091	0.9969200
0.272	0.0343748	1292	1.0031442	236	3.6650628	0.0136089	0.9968971
0.273	0.0345040	1292	1.0031678	236	3.6515535	0.0135093	0.9968741
0.274	0.0346333	1293	1.0031915	237	3.6381423	0.0134112	0.9968510
0.275	0.0347626	1293	1.0032153	238	3.6248283	0.0133140	0.9968278
0.276	0.0348919	1293	1.0032392	239	3.6116106	0.0132177	0.9968045
0.277	0.0350212	1293	1.0032632	240	3.5984880	0.0131226	0.9967812
0.278	0.0351506	1294	1.0032873	241	3.5854594	0.0130286	0.9967577
0.279	0.0352800	1294	1.0033115	242	3.5725240	0.0129354	0.9967342
0.280	0.0354094	1294	1.0033358	243	3.5596805	0.0128435	0.9967106
0.281	0.0355389	1295	1.0033602	244	3.5469284	0.0127521	0.9966869
0.282	0.0356684	1295	1.0033846	244	3.5342662	0.0126622	0.9966631
0.283	0.0357979	1295	1.0034091	245	3.5216931	0.0125731	0.9966392
0.284	0.0359275	1296	1.0034338	247	3.5092084	0.0124847	0.9966152
0.285	0.0360571	1296	1.0034585	247	3.4968109	0.0123975	0.9965911
0.286	0.0361867	1296	1.0034834	249	3.4845001	0.0123108	0.9965670
0.287	0.0363164	1297	1.0035083	249	3.4722744	0.0122257	0.9965428
0.288	0.0364461	1297	1.0035334	251	3.4601336	0.0121408	0.9965185
0.289	0.0365758	1297	1.0035585	251	3.4480763	0.0120573	0.9964941
0.290	0.0367056	1298	1.0035838	253	3.4361020	0.0119743	0.9964696
0.291	0.0368354	1298	1.0036091	253	3.4242097	0.0118923	0.9964450
0.292	0.0369653	1299	1.0036346	255	3.4123985	0.0118112	0.9964204
0.293	0.0370952	1299	1.0036601	255	3.4006676	0.0117309	0.9963956
0.294	0.0372251	1299	1.0036857	256	3.3890162	0.0116514	0.9963708
0.295	0.0373550	1299	1.0037114	257	3.3774435	0.0115727	0.9963458
0.296	0.0374850	1300	1.0037372	258	3.3659488	0.0114947	0.9963208
0.297	0.0376150	1300	1.0037631	259	3.3545310	0.0114178	0.9962957
0.298	0.0377451	1301	1.0037891	260	3.3431896	0.0113414	0.9962705
0.299	0.0378752	1301	1.0038152	261	3.3319239	0.0112657	0.9962452
0.300	0.0380053	1301	1.0038414	262	3.3207331	0.0111908	0.9962199

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sW}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.300	0.0380053		1.0038414		3.3207331		0.9962199
0.301	0.0381355	1302	1.0038677	263	3.3096161	0.0111170	0.9961944
0.302	0.0382657	1302	1.0038941	264	3.2985726	0.0110435	0.9961689
0.303	0.0383959	1302	1.0039206	265	3.2876017	0.0109709	0.9961433
0.304	0.0385262	1303	1.0039472	266	3.2767026	0.0108991	0.9961176
0.305	0.0386565	1303	1.0039739	267	3.2658749	0.0108277	0.9960918
0.306	0.0387868	1303	1.0040006	267	3.2551174	0.0107575	0.9960659
0.307	0.0389172	1304	1.0040275	269	3.2444298	0.0106876	0.9960399
0.308	0.0390476	1304	1.0040544	269	3.2338113	0.0106185	0.9960139
0.309	0.0391781	1305	1.0040815	271	3.2232613	0.0105500	0.9959877
0.310	0.0393086	1305	1.0041086	271	3.2127789	0.0104824	0.9959615
0.311	0.0394391	1305	1.0041359	273	3.2023639	0.0104150	0.9959351
0.312	0.0395697	1306	1.0041632	273	3.1920152	0.0103487	0.9959087
0.313	0.0397003	1306	1.0041907	275	3.1817324	0.0102828	0.9958822
0.314	0.0398309	1306	1.0042182	275	3.1715148	0.0102176	0.9958556
0.315	0.0399616	1307	1.0042459	277	3.1613619	0.0101529	0.9958289
0.316	0.0400923	1307	1.0042736	277	3.1512728	0.0100891	0.9958022
0.317	0.0402231	1308	1.0043015	279	3.1412473	0.0100255	0.9957753
0.318	0.0403539	1308	1.0043294	279	3.1312844	0.0099629	0.9957484
0.319	0.0404847	1308	1.0043574	280	3.1213837	0.0099007	0.9957214
0.320	0.0406156	1309	1.0043855	281	3.1115446	0.0098391	0.9956943
0.321	0.0407465	1309	1.0044137	282	3.1017665	0.0097781	0.9956670
0.322	0.0408774	1309	1.0044420	283	3.0920489	0.0097176	0.9956397
0.323	0.0410084	1310	1.0044705	285	3.0823913	0.0096576	0.9956124
0.324	0.0411394	1310	1.0044990	285	3.0727929	0.0095984	0.9955849
0.325	0.0412705	1311	1.0045277	287	3.0632535	0.0095394	0.9955573
0.326	0.0414016	1311	1.0045564	287	3.0537722	0.0094813	0.9955297
0.327	0.0415327	1311	1.0045852	288	3.0443486	0.0094236	0.9955020
0.328	0.0416639	1312	1.0046141	289	3.0349822	0.0093664	0.9954742
0.329	0.0417951	1312	1.0046431	290	3.0256725	0.0093097	0.9954462
0.330	0.0419264	1313	1.0046722	291	3.0164189	0.0092536	0.9954182
0.331	0.0420577	1313	1.0047015	293	3.0072212	0.0091977	0.9953902
0.332	0.0421891	1314	1.0047308	293	2.9980783	0.0091429	0.9953620
0.333	0.0423205	1314	1.0047602	294	2.9889902	0.0090881	0.9953337
0.334	0.0424519	1314	1.0047897	295	2.9799562	0.0090340	0.9953054
0.335	0.0425833	1314	1.0048193	296	2.9709760	0.0089802	0.9952769
0.336	0.0427148	1315	1.0048490	297	2.9620489	0.0089271	0.9952484
0.337	0.0428464	1316	1.0048789	299	2.9531746	0.0088743	0.9952198
0.338	0.0429780	1316	1.0049088	299	2.9443524	0.0088222	0.9951911
0.339	0.0431096	1316	1.0049388	300	2.9355821	0.0087703	0.9951623
0.340	0.0432413	1317	1.0049689	301	2.9268630	0.0087191	0.9951334
0.341	0.0433730	1317	1.0049991	302	2.9181949	0.0086681	0.9951044
0.342	0.0435048	1318	1.0050294	303	2.9095771	0.0086178	0.9950754
0.343	0.0436366	1318	1.0050598	304	2.9010094	0.0085677	0.9950462
0.344	0.0437684	1318	1.0050903	305	2.8924912	0.0085182	0.9950170
0.345	0.0439003	1319	1.0051209	306	2.8840222	0.0084690	0.9949877
0.346	0.0440322	1319	1.0051516	307	2.8756019	0.0084203	0.9949583
0.347	0.0441642	1320	1.0051825	309	2.8672299	0.0083720	0.9949287
0.348	0.0442962	1320	1.0052134	309	2.8589056	0.0083243	0.9948991
0.349	0.0444282	1320	1.0052444	310	2.8506289	0.0082767	0.9948694
0.350	0.0445603	1321	1.0052755	311	2.8423992	0.0082297	0.9948397

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.350	0.0445603	1321	1.0052755	312	2.8423992	0.0081831	0.9948397
0.351	0.0446924	1322	1.0053067	313	2.8342161	0.0081369	0.9948098
0.352	0.0448246	1322	1.0053380	315	2.8260792	0.0080909	0.9947799
0.353	0.0449568	1323	1.0053695	315	2.8179883	0.0080455	0.9947499
0.354	0.0450891	1323	1.0054010	316	2.8099428	0.0080005	0.9947198
0.355	0.0452214	1324	1.0054326	317	2.8019423	0.0079559	0.9946895
0.356	0.0453538	1324	1.0054643	319	2.7939864	0.0079113	0.9946592
0.357	0.0454862	1324	1.0054962	319	2.7860751	0.0078675	0.9946288
0.358	0.0456186	1325	1.0055281	321	2.7782076	0.0078238	0.9945983
0.359	0.0457511	1326	1.0055602	321	2.7703838	0.0077808	0.9945677
0.360	0.0458837	1326	1.0055923	323	2.7626030	0.0077377	0.9945371
0.361	0.0460163	1326	1.0056246	323	2.7548653	0.0076955	0.9945063
0.362	0.0461489	1327	1.0056569	324	2.7471698	0.0076532	0.9944755
0.363	0.0462816	1327	1.0056893	325	2.7395166	0.0076114	0.9944445
0.364	0.0464143	1328	1.0057218	327	2.7319052	0.0075698	0.9944135
0.365	0.0465471	1328	1.0057545	327	2.7243354	0.0075289	0.9943824
0.366	0.0466799	1328	1.0057872	329	2.7168065	0.0074879	0.9943512
0.367	0.0468127	1329	1.0058201	330	2.7093186	0.0074475	0.9943199
0.368	0.0469456	1329	1.0058531	331	2.7018711	0.0074074	0.9942886
0.369	0.0470785	1330	1.0058862	331	2.6944637	0.0073677	0.9942571
0.370	0.0472115	1330	1.0059193	333	2.6870960	0.0073281	0.9942255
0.371	0.0473445	1331	1.0059526	333	2.6797679	0.0072891	0.9941939
0.372	0.0474776	1331	1.0059859	335	2.6724788	0.0072501	0.9941621
0.373	0.0476107	1332	1.0060194	336	2.6652287	0.0072116	0.9941303
0.374	0.0477439	1332	1.0060530	337	2.6580171	0.0071734	0.9940984
0.375	0.0478771	1333	1.0060867	337	2.6508437	0.0071356	0.9940644
0.376	0.0480104	1333	1.0061204	339	2.6437081	0.0070979	0.9940342
0.377	0.0481437	1334	1.0061543	340	2.6366102	0.0070606	0.9940020
0.378	0.0482771	1334	1.0061883	341	2.6295496	0.0070235	0.9939697
0.379	0.0484105	1335	1.0062224	342	2.6225261	0.0069868	0.9939374
0.380	0.0485440	1335	1.0062566	344	2.6155393	0.0069502	0.9939049
0.381	0.0486775	1336	1.0062910	344	2.6085891	0.0069143	0.9938724
0.382	0.0488111	1336	1.0063254	345	2.6016748	0.0068784	0.9938398
0.383	0.0489447	1336	1.0063599	346	2.5947964	0.0068427	0.9938070
0.384	0.0490783	1337	1.0063945	348	2.5879537	0.0068074	0.9937742
0.385	0.0492120	1338	1.0064293	348	2.5811463	0.0067724	0.9937413
0.386	0.0493458	1338	1.0064641	350	2.5743739	0.0067376	0.9937083
0.387	0.0494796	1338	1.0064991	350	2.5676363	0.0067032	0.9936752
0.388	0.0496134	1339	1.0065341	352	2.5609331	0.0066688	0.9936420
0.389	0.0497473	1339	1.0065693	352	2.5542643	0.0066351	0.9936088
0.390	0.0498812	1340	1.0066045	354	2.5476292	0.0066011	0.9935754
0.391	0.0500152	1341	1.0066399	354	2.5410281	0.0065679	0.9935420
0.392	0.0501493	1341	1.0066753	356	2.5344602	0.0065346	0.9935084
0.393	0.0502834	1342	1.0067109	357	2.5279256	0.0065016	0.9934748
0.394	0.0504176	1342	1.0067466	358	2.5214240	0.0064690	0.9934411
0.395	0.0505518	1342	1.0067824	359	2.5149550	0.0064366	0.9934072
0.396	0.0506860	1343	1.0068183	360	2.5085184	0.0064042	0.9933733
0.397	0.0508203	1343	1.0068543	361	2.5021142	0.0063724	0.9933393
0.398	0.0509546	1344	1.0068904	363	2.4957418	0.0063406	0.9933052
0.399	0.0510890	1345	1.0069267	363	2.4894012	0.0063092	0.9932710
0.400	0.0512235		1.0069630		2.4830920		0.9932368

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$= \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
.400	0.0512235		1.0069630		2.4830920		0.9932368
.401	0.0513580	1345	1.0069995	365	2.4768141	0.0062779	0.9932024
.402	0.0514925	1345	1.0070360	365	2.4705672	0.0062469	0.9931680
.403	0.0516271	1346	1.0070727	367	2.4643511	0.0062161	0.9931335
.404	0.0517618	1347	1.0071094	367	2.4581654	0.0061857	0.9930988
.405	0.0518965	1347	1.0071463	369	2.4520101	0.0061553	0.9930641
.406	0.0520313	1348	1.0071832	369	2.4458848	0.0061253	0.9930292
.407	0.0521661	1348	1.0072203	371	2.4397896	0.0060952	0.9929943
.408	0.0523010	1349	1.0072575	372	2.4337239	0.0060657	0.9929593
.409	0.0524359	1349	1.0072948	373	2.4276876	0.0060363	0.9929242
.410	0.0525709	1350	1.0073322	374	2.4216806	0.0060070	0.9928890
.411	0.0527059	1350	1.0073698	376	2.4157028	0.0059778	0.9928538
.412	0.0528410	1351	1.0074074	376	2.4097535	0.0059493	0.9928184
.413	0.0529761	1351	1.0074452	378	2.4038329	0.0059206	0.9927830
.414	0.0531113	1352	1.0074830	378	2.3979407	0.0058922	0.9927474
.415	0.0532465	1352	1.0075210	380	2.3920766	0.0058641	0.9927118
.416	0.0533818	1353	1.0075590	380	2.3862406	0.0058360	0.9926761
.417	0.0535172	1354	1.0075972	382	2.3804322	0.0058084	0.9926403
.418	0.0536526	1354	1.0076355	383	2.3746515	0.0057807	0.9926044
.419	0.0537881	1355	1.0076739	384	2.3688982	0.0057533	0.9925684
.420	0.0539236	1355	1.0077124	385	2.3631720	0.0057262	0.9925323
.421	0.0540591	1355	1.0077510	386	2.3574728	0.0056992	0.9924961
.422	0.0541947	1356	1.0077897	387	2.3518004	0.0056724	0.9924598
.423	0.0543304	1357	1.0078286	389	2.3461546	0.0056458	0.9924234
.424	0.0544661	1357	1.0078675	389	2.3405352	0.0056194	0.9923869
.425	0.0546019	1358	1.0079066	391	2.3349420	0.0055932	0.9923504
.426	0.0547377	1358	1.0079457	391	2.3293749	0.0055671	0.9923137
.427	0.0548736	1359	1.0079850	393	2.3238337	0.0055412	0.9922770
.428	0.0550096	1360	1.0080244	394	2.3183181	0.0055156	0.9922401
.429	0.0551456	1360	1.0080640	396	2.3128280	0.0054901	0.9922032
.430	0.0552817	1361	1.0081036	396	2.3073633	0.0054647	0.9921662
.431	0.0554178	1361	1.0081433	397	2.3019236	0.0054397	0.9921291
.432	0.0555540	1362	1.0081831	398	2.2965090	0.0054146	0.9920919
.433	0.0556902	1362	1.0082231	400	2.2911192	0.0053898	0.9920546
.434	0.0558265	1363	1.0082631	400	2.2857540	0.0053652	0.9920172
.435	0.0559629	1364	1.0083033	402	2.2804132	0.0053408	0.9919797
.436	0.0560993	1364	1.0083436	403	2.2750967	0.0053165	0.9919421
.437	0.0562358	1365	1.0083840	404	2.2698044	0.0052923	0.9919045
.438	0.0563723	1365	1.0084245	405	2.2645360	0.0052684	0.9918667
.439	0.0565089	1366	1.0084652	407	2.2592914	0.0052446	0.9918289
.440	0.0566455	1366	1.0085059	407	2.2540703	0.0052211	0.9917909
.441	0.0567822	1367	1.0085468	409	2.2488728	0.0051975	0.9917529
.442	0.0569190	1368	1.0085878	410	2.2436986	0.0051742	0.9917148
.443	0.0570558	1368	1.0086289	411	2.2385476	0.0051510	0.9916766
.444	0.0571927	1369	1.0086701	412	2.2334195	0.0051281	0.9916383
.445	0.0573296	1369	1.0087114	413	2.2283143	0.0051052	0.9915999
.446	0.0574666	1370	1.0087528	414	2.2232317	0.0050826	0.9915614
.447	0.0576037	1371	1.0087943	415	2.2181718	0.0050599	0.9915228
.448	0.0577408	1371	1.0088360	417	2.2131341	0.0050377	0.9914841
.449	0.0578780	1372	1.0088778	418	2.2081186	0.0050155	0.9914453
.450	0.0580152	1372	1.0089197	419	2.2031254	0.0049932	0.9914064

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y}$ $\frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.450	0.0580152	1373	1.0089197	420	2.2031254	0.0049714	0.9914064
0.451	0.0581525	1374	1.0089617	421	2.1981540	0.0049496	0.9913674
0.452	0.0582899	1374	1.0090038	422	2.1932044	0.0049279	0.9913284
0.453	0.0584273	1375	1.0090460	424	2.1882765	0.0049064	0.9912892
0.454	0.0585648	1375	1.0090884	425	2.1833701	0.0048851	0.9912500
0.455	0.0587023	1376	1.0091309	426	2.1784850	0.0048638	0.9912107
0.456	0.0588399	1377	1.0091735	427	2.1736212	0.0048428	0.9911713
0.457	0.0589776	1377	1.0092162	428	2.1687784	0.0048219	0.9911317
0.458	0.0591153	1378	1.0092590	429	2.1639565	0.0048009	0.9910921
0.459	0.0592531	1379	1.0093019	431	2.1591556	0.0047804	0.9910524
0.460	0.0593910	1379	1.0093450	431	2.1543752	0.0047599	0.9910126
0.461	0.0595289	1380	1.0093881	433	2.1496153	0.0047394	0.9909727
0.462	0.0596669	1380	1.0094314	434	2.1448759	0.0047192	0.9909327
0.463	0.0598049	1381	1.0094748	436	2.1401567	0.0046989	0.9908926
0.464	0.0599430	1382	1.0095184	436	2.1354578	0.0046791	0.9908524
0.465	0.0600812	1382	1.0095620	438	2.1307787	0.0046591	0.9908121
0.466	0.0602194	1383	1.0096058	438	2.1261196	0.0046394	0.9907717
0.467	0.0603577	1383	1.0096496	440	2.1214802	0.0046197	0.9907313
0.468	0.0604960	1384	1.0096936	441	2.1168605	0.0046002	0.9906907
0.469	0.0606344	1385	1.0097377	443	2.1122603	0.0045808	0.9906501
0.470	0.0607729	1386	1.0097820	443	2.1076795	0.0045616	0.9906094
0.471	0.0609115	1386	1.0098263	445	2.1031179	0.0045425	0.9905685
0.472	0.0610501	1387	1.0098708	446	2.0985754	0.0045234	0.9905276
0.473	0.0611888	1387	1.0099154	447	2.0940520	0.0045047	0.9904866
0.474	0.0613275	1388	1.0099601	448	2.0895473	0.0044857	0.9904454
0.475	0.0614663	1389	1.0100049	450	2.0850616	0.0044672	0.9904042
0.476	0.0616052	1389	1.0100499	450	2.0805944	0.0044487	0.9903629
0.477	0.0617441	1390	1.0100949	452	2.0761457	0.0044303	0.9903215
0.478	0.0618831	1391	1.0101401	453	2.0717154	0.0044119	0.9902800
0.479	0.0620222	1391	1.0101854	454	2.0673035	0.0043937	0.9902384
0.480	0.0621613	1392	1.0102308	455	2.0629098	0.0043757	0.9901967
0.481	0.0623005	1393	1.0102763	457	2.0585341	0.0043577	0.9901549
0.482	0.0624398	1394	1.0103220	458	2.0541764	0.0043398	0.9901130
0.483	0.0625792	1394	1.0103678	460	2.0498366	0.0043221	0.9900710
0.484	0.0627186	1395	1.0104138	460	2.0455145	0.0043045	0.9900290
0.485	0.0628581	1395	1.0104598	461	2.0412100	0.0042871	0.9899868
0.486	0.0629976	1396	1.0105059	463	2.0369229	0.0042695	0.9899445
0.487	0.0631372	1397	1.0105522	464	2.0326534	0.0042523	0.9899022
0.488	0.0632769	1397	1.0105986	465	2.0284011	0.0042351	0.9898597
0.489	0.0634166	1398	1.0106451	467	2.0241660	0.0042179	0.9898172
0.490	0.0635564	1399	1.0106918	467	2.0199481	0.0042010	0.9897746
0.491	0.0636963	1399	1.0107385	469	2.0157471	0.0041841	0.9897318
0.492	0.0638362	1400	1.0107854	470	2.0115630	0.0041673	0.9896890
0.493	0.0639762	1401	1.0108324	472	2.0073957	0.0041506	0.9896461
0.494	0.0641163	1402	1.0108796	472	2.0032451	0.0041341	0.9896031
0.495	0.0642565	1402	1.0109268	474	1.9991110	0.0041176	0.9895599
0.496	0.0643967	1403	1.0109742	475	1.9949934	0.0041012	0.9895167
0.497	0.0645370	1404	1.0110217	476	1.9908922	0.0040850	0.9894734
0.498	0.0646774	1404	1.0110693	478	1.9868072	0.0040687	0.9894300
0.499	0.0648178	1405	1.0111171	479	1.9827385	0.0040527	0.9893865
0.500	0.0649583		1.0111650		1.9786858		0.9893429

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y}$ $\frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.500	0.0649583		1.0111650		1.9786858		0.9893429
0.501	0.0650989	1406	1.0112130	480	1.9746492	0.0040366	0.9892992
0.502	0.0652395	1406	1.0112611	481	1.9706284	0.0040208	0.9892554
0.503	0.0653802	1407	1.0113093	482	1.9666233	0.0040051	0.9892115
0.504	0.0655210	1408	1.0113577	484	1.9626340	0.0039893	0.9891676
0.505	0.0656619	1409	1.0114062	485	1.9586604	0.0039736	0.9891235
0.506	0.0658028	1409	1.0114549	487	1.9547023	0.0039581	0.9890793
0.507	0.0659438	1410	1.0115036	487	1.9507595	0.0039428	0.9890350
0.508	0.0660849	1411	1.0115525	489	1.9468321	0.0039274	0.9889907
0.509	0.0662261	1412	1.0116015	490	1.9429199	0.0039122	0.9889462
0.510	0.0663673	1412	1.0116507	492	1.9390229	0.0038970	0.9889017
0.511	0.0665086	1413	1.0116999	492	1.9351409	0.0038820	0.9888570
0.512	0.0666500	1414	1.0117493	494	1.9312739	0.0038670	0.9888122
0.513	0.0667915	1415	1.0117988	495	1.9274218	0.0038521	0.9887674
0.514	0.0669330	1415	1.0118485	497	1.9235846	0.0038372	0.9887225
0.515	0.0670746	1416	1.0118982	497	1.9197620	0.0038226	0.9886774
0.516	0.0672162	1416	1.0119481	499	1.9159540	0.0038080	0.9886323
0.517	0.0673580	1418	1.0119981	500	1.9121606	0.0037934	0.9885870
0.518	0.0674998	1418	1.0120483	502	1.9083817	0.0037789	0.9885417
0.519	0.0676417	1419	1.0120986	503	1.9046171	0.0037646	0.9884963
0.520	0.0677836	1419	1.0121490	504	1.9008669	0.0037502	0.9884508
0.521	0.0679257	1421	1.0121995	505	1.8971307	0.0037362	0.9884051
0.522	0.0680678	1421	1.0122502	507	1.8934089	0.0037218	0.9883594
0.523	0.0682100	1422	1.0123010	508	1.8897009	0.0037080	0.9883136
0.524	0.0683522	1422	1.0123519	509	1.8860070	0.0036939	0.9882677
0.525	0.0684946	1424	1.0124030	511	1.8823270	0.0036800	0.9882217
0.526	0.0686370	1424	1.0124542	512	1.8786608	0.0036662	0.9881756
0.527	0.0687795	1425	1.0125055	513	1.8750083	0.0036525	0.9881294
0.528	0.0689220	1425	1.0125570	515	1.8713695	0.0036388	0.9880831
0.529	0.0690647	1427	1.0126086	516	1.8677442	0.0036253	0.9880367
0.530	0.0692074	1427	1.0126603	517	1.8641324	0.0036118	0.9879902
0.531	0.0693502	1428	1.0127121	518	1.8605341	0.0035983	0.9879436
0.532	0.0694930	1428	1.0127641	520	1.8569491	0.0035850	0.9878969
0.533	0.0696360	1430	1.0128162	521	1.8533773	0.0035718	0.9878501
0.534	0.0697790	1430	1.0128684	522	1.8498188	0.0035585	0.9878032
0.535	0.0699221	1431	1.0129208	524	1.8462734	0.0035454	0.9877562
0.536	0.0700653	1432	1.0129733	525	1.8427410	0.0035324	0.9877091
0.537	0.0702086	1433	1.0130259	526	1.8392215	0.0035195	0.9876619
0.538	0.0703520	1434	1.0130787	528	1.8357150	0.0035065	0.9876146
0.539	0.0704954	1434	1.0131316	529	1.8322214	0.0034936	0.9875672
0.540	0.0706389	1435	1.0131846	530	1.8287404	0.0034810	0.9875198
0.541	0.0707825	1436	1.0132378	532	1.8252721	0.0034683	0.9874722
0.542	0.0709262	1437	1.0132911	533	1.8218165	0.0034556	0.9874245
0.543	0.0710700	1438	1.0133445	534	1.8183734	0.0034431	0.9873767
0.544	0.0712138	1438	1.0133981	536	1.8149428	0.0034306	0.9873289
0.545	0.0713577	1439	1.0134518	537	1.8115247	0.0034181	0.9872809
0.546	0.0715017	1440	1.0135057	539	1.8081188	0.0034059	0.9872329
0.547	0.0716458	1441	1.0135596	539	1.8047252	0.0033936	0.9871847
0.548	0.0717899	1441	1.0136137	541	1.8013438	0.0033814	0.9871364
0.549	0.0719342	1443	1.0136680	543	1.7979745	0.0033693	0.9870880
0.550	0.0720785	1443	1.0137224	544	1.7946175	0.0033570	0.9870396

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.550	0.0720785	1444	1.0137224	545	1.7946175	0.0033452	0.9870396
0.551	0.0722229	1445	1.0137769	546	1.7912723	0.0033332	0.9869910
0.552	0.0723674	1446	1.0138315	548	1.7879391	0.0033214	0.9869424
0.553	0.0725120	1446	1.0138863	550	1.7846177	0.0033095	0.9868936
0.554	0.0726566	1448	1.0139413	550	1.7813082	0.0032978	0.9868447
0.555	0.0728014	1448	1.0139963	552	1.7780104	0.0032861	0.9867957
0.556	0.0729462	1449	1.0140515	554	1.7747243	0.0032745	0.9867467
0.557	0.0730911	1450	1.0141069	555	1.7714498	0.0032629	0.9866975
0.558	0.0732361	1451	1.0141624	556	1.7681869	0.0032514	0.9866483
0.559	0.0733812	1451	1.0142180	557	1.7649355	0.0032400	0.9865989
0.560	0.0735263	1453	1.0142737	559	1.7616955	0.0032286	0.9865495
0.561	0.0736716	1453	1.0143296	561	1.7584669	0.0032173	0.9864999
0.562	0.0738169	1454	1.0143857	561	1.7552496	0.0032060	0.9864503
0.563	0.0739623	1455	1.0144418	563	1.7520436	0.0031949	0.9864005
0.564	0.0741078	1456	1.0144981	565	1.7488487	0.0031837	0.9863507
0.565	0.0742534	1457	1.0145546	566	1.7456650	0.0031727	0.9863007
0.566	0.0743991	1458	1.0146112	567	1.7424923	0.0031616	0.9862507
0.567	0.0745449	1458	1.0146679	569	1.7393307	0.0031507	0.9862005
0.568	0.0746907	1459	1.0147248	570	1.7361800	0.0031398	0.9861503
0.569	0.0748366	1460	1.0147818	572	1.7330402	0.0031289	0.9860999
0.570	0.0749826	1461	1.0148390	573	1.7299113	0.0031182	0.9860494
0.571	0.0751287	1462	1.0148963	574	1.7267931	0.0031074	0.9859988
0.572	0.0752749	1463	1.0149537	576	1.7236857	0.0030968	0.9859482
0.573	0.0754212	1464	1.0150113	577	1.7205889	0.0030861	0.9858974
0.574	0.0755676	1465	1.0150690	579	1.7175028	0.0030756	0.9858466
0.575	0.0757141	1465	1.0151269	580	1.7144272	0.0030651	0.9857956
0.576	0.0758606	1467	1.0151849	581	1.7113621	0.0030547	0.9857446
0.577	0.0760073	1467	1.0152430	583	1.7083074	0.0030442	0.9856934
0.578	0.0761540	1468	1.0153013	584	1.7052632	0.0030339	0.9856421
0.579	0.0763008	1469	1.0153597	586	1.7022293	0.0030236	0.9855908
0.580	0.0764477	1470	1.0154183	587	1.6992057	0.0030134	0.9855393
0.581	0.0765947	1471	1.0154770	589	1.6961923	0.0030032	0.9854877
0.582	0.0767418	1472	1.0155359	590	1.6931891	0.0029930	0.9854361
0.583	0.0768890	1473	1.0155949	592	1.6901961	0.0029830	0.9853843
0.584	0.0770363	1474	1.0156541	593	1.6872131	0.0029729	0.9853325
0.585	0.0771837	1474	1.0157134	594	1.6842402	0.0029630	0.9852805
0.586	0.0773311	1476	1.0157728	596	1.6812772	0.0029531	0.9852284
0.587	0.0774787	1476	1.0158324	598	1.6783241	0.0029432	0.9851762
0.588	0.0776263	1478	1.0158922	599	1.6753809	0.0029334	0.9851240
0.589	0.0777741	1478	1.0159521	600	1.6724475	0.0029236	0.9850716
0.590	0.0779219	1479	1.0160121	602	1.6695239	0.0029139	0.9850191
0.591	0.0780698	1480	1.0160723	603	1.6666100	0.0029042	0.9849665
0.592	0.0782178	1481	1.0161326	605	1.6637058	0.0028946	0.9849138
0.593	0.0783659	1482	1.0161931	606	1.6608112	0.0028850	0.9848610
0.594	0.0785141	1483	1.0162537	608	1.6579262	0.0028755	0.9848082
0.595	0.0786624	1484	1.0163145	609	1.6550507	0.0028660	0.9847552
0.596	0.0788108	1485	1.0163754	611	1.6521847	0.0028566	0.9847021
0.597	0.0789593	1486	1.0164365	612	1.6493281	0.0028472	0.9846489
0.598	0.0791079	1487	1.0164977	614	1.6464809	0.0028379	0.9845956
0.599	0.0792566	1488	1.0165591	615	1.6436430	0.0028285	0.9845422
0.600	0.0794054		1.0166206		1.6408145		0.9844887

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.600	0.0794054	1489	1.0166206	617	1.6408145	0.0028194	0.9844887
0.601	0.0795543	1489	1.0166823	618	1.6379951	0.0028101	0.9844351
0.602	0.0797032	1491	1.0167441	620	1.6351850	0.0028009	0.9843814
0.603	0.0798523	1491	1.0168061	621	1.6323841	0.0027919	0.9843276
0.604	0.0800014	1493	1.0168682	623	1.6295922	0.0027828	0.9842737
0.605	0.0801507	1494	1.0169305	624	1.6268094	0.0027739	0.9842197
0.606	0.0803001	1495	1.0169929	626	1.6240355	0.0027648	0.9841655
0.607	0.0804496	1495	1.0170555	627	1.6212707	0.0027559	0.9841113
0.608	0.0805991	1497	1.0171182	629	1.6185148	0.0027471	0.9840570
0.609	0.0807488	1497	1.0171811	630	1.6157677	0.0027382	0.9840025
0.610	0.0808985	1499	1.0172441	632	1.6130295	0.0027294	0.9839480
0.611	0.0810484	1499	1.0173073	633	1.6103001	0.0027207	0.9838934
0.612	0.0811983	1501	1.0171706	635	1.6075794	0.0027119	0.9838386
0.613	0.0813484	1501	1.0174341	637	1.6048675	0.0027032	0.9837838
0.614	0.0814985	1503	1.0174978	638	1.6021643	0.0026947	0.9837289
0.615	0.0816488	1503	1.0175616	639	1.5994696	0.0026861	0.9836738
0.616	0.0817991	1505	1.0176255	641	1.5967835	0.0026776	0.9836186
0.617	0.0819496	1505	1.0176896	643	1.5941059	0.0026690	0.9835633
0.618	0.0821001	1507	1.0177539	644	1.5914369	0.0026606	0.9835080
0.619	0.0822508	1507	1.0178183	646	1.5887763	0.0026521	0.9834525
0.620	0.0824015	1509	1.0178829	647	1.5861242	0.0026438	0.9833970
0.621	0.0825524	1509	1.0179476	649	1.5834804	0.0026355	0.9833413
0.622	0.0827033	1511	1.0180125	651	1.5808449	0.0026272	0.9832855
0.623	0.0828544	1512	1.0180776	652	1.5782177	0.0026189	0.9832296
0.624	0.0830056	1513	1.0181428	654	1.5755988	0.0026107	0.9831737
0.625	0.0831569	1514	1.0182082	655	1.5729881	0.0026026	0.9831176
0.626	0.0833083	1515	1.0182737	657	1.5703855	0.0025944	0.9830614
0.627	0.0834598	1516	1.0183394	658	1.5677911	0.0025863	0.9830051
0.628	0.0836114	1518	1.0184052	660	1.5652048	0.0025783	0.9829486
0.629	0.0837632	1518	1.0184712	662	1.5626265	0.0025702	0.9828921
0.630	0.0839150	1519	1.0185374	663	1.5600563	0.0025622	0.9828355
0.631	0.0840669	1519	1.0186037	665	1.5574941	0.0025543	0.9827788
0.632	0.0842188	1521	1.0186702	666	1.5549398	0.0025464	0.9827220
0.633	0.0843709	1522	1.0187368	668	1.5523934	0.0025385	0.9826650
0.634	0.0845231	1524	1.0188036	670	1.5498549	0.0025307	0.9826080
0.635	0.0846755	1524	1.0188706	671	1.5473242	0.0025230	0.9825508
0.636	0.0848279	1526	1.0189377	673	1.5448012	0.0025151	0.9824936
0.637	0.0849805	1526	1.0190050	675	1.5422861	0.0025074	0.9824362
0.638	0.0851331	1528	1.0190725	676	1.5397787	0.0024998	0.9823788
0.639	0.0852859	1528	1.0191401	678	1.5372789	0.0024921	0.9823212
0.640	0.0854387	1530	1.0192079	680	1.5347868	0.0024845	0.9822636
0.641	0.0855917	1531	1.0192759	681	1.5323023	0.0024769	0.9822058
0.642	0.0857448	1532	1.0193440	683	1.5298254	0.0024694	0.9821479
0.643	0.0858980	1533	1.0194123	684	1.5273560	0.0024619	0.9820900
0.644	0.0860513	1534	1.0194807	686	1.5248941	0.0024544	0.9820318
0.645	0.0862047	1535	1.0195493	688	1.5224397	0.0024469	0.9819736
0.646	0.0863582	1537	1.0196181	689	1.5199928	0.0024396	0.9819153
0.647	0.0865119	1537	1.0196870	691	1.5175532	0.0024322	0.9818569
0.648	0.0866656	1539	1.0197561	692	1.5151210	0.0024249	0.9817984
0.649	0.0868195	1539	1.0198253	694	1.5126961	0.0024176	0.9817397
0.650	0.0869734		1.0198947		1.5102785		0.9816810

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.650	0.0869734	1541	1.0198947	696	1.5102785	0.0024103	0.9816810
0.651	0.0871275	1542	1.0199643	698	1.5078682	0.0024031	0.9816222
0.652	0.0872817	1543	1.0200341	699	1.5054651	0.0023959	0.9815632
0.653	0.0874360	1545	1.0201040	701	1.5030692	0.0023888	0.9815042
0.654	0.0875905	1545	1.0201741	703	1.5006804	0.0023816	0.9814450
0.655	0.0877450	1547	1.0202444	704	1.4982988	0.0023746	0.9813857
0.656	0.0878997	1548	1.0203148	706	1.4959242	0.0023674	0.9813263
0.657	0.0880545	1549	1.0203854	708	1.4935568	0.0023604	0.9812668
0.658	0.0882094	1550	1.0204562	710	1.4911964	0.0023534	0.9812072
0.659	0.0883644	1551	1.0205272	711	1.4888430	0.0023465	0.9811475
0.660	0.0885195	1552	1.0205983	713	1.4864965	0.0023395	0.9810877
0.661	0.0886747	1554	1.0206696	715	1.4841570	0.0023326	0.9810278
0.662	0.0888301	1555	1.0207411	716	1.4818244	0.0023257	0.9809678
0.663	0.0889856	1556	1.0208127	718	1.4794987	0.0023189	0.9809076
0.664	0.0891412	1557	1.0208845	720	1.4771798	0.0023120	0.9808474
0.665	0.0892969	1558	1.0209565	722	1.4748678	0.0023053	0.9807871
0.666	0.0894527	1559	1.0210287	723	1.4725625	0.0022985	0.9807266
0.667	0.0896086	1561	1.0211010	725	1.4702640	0.0022919	0.9806661
0.668	0.0897647	1562	1.0211735	727	1.4679721	0.0022852	0.9806054
0.669	0.0899209	1563	1.0212462	728	1.4656869	0.0022785	0.9805446
0.670	0.0900772	1564	1.0213190	730	1.4634084	0.0022719	0.9804836
0.671	0.0902336	1565	1.0213920	732	1.4611365	0.0022652	0.9804226
0.672	0.0903901	1567	1.0214652	734	1.4588713	0.0022587	0.9803615
0.673	0.0905468	1568	1.0215386	736	1.4566126	0.0022521	0.9803003
0.674	0.0907036	1569	1.0216122	737	1.4543605	0.0022456	0.9802390
0.675	0.0908605	1570	1.0216859	739	1.4521149	0.0022392	0.9801776
0.676	0.0910175	1572	1.0217598	741	1.4498757	0.0022327	0.9801160
0.677	0.0911747	1572	1.0218339	743	1.4476430	0.0022262	0.9800543
0.678	0.0913319	1574	1.0219082	745	1.4454168	0.0022199	0.9799926
0.679	0.0914893	1575	1.0219827	746	1.4431969	0.0022135	0.9799307
0.680	0.0916468	1576	1.0220573	748	1.4409834	0.0022072	0.9798687
0.681	0.0918044	1578	1.0221321	750	1.4387762	0.0022008	0.9798066
0.682	0.0919622	1579	1.0222071	752	1.4365754	0.0021946	0.9797444
0.683	0.0921201	1580	1.0222823	753	1.4343808	0.0021883	0.9796821
0.684	0.0922781	1581	1.0223576	755	1.4321925	0.0021821	0.9796197
0.685	0.0924362	1583	1.0224331	757	1.4300104	0.0021759	0.9795572
0.686	0.0925945	1584	1.0225088	759	1.4278345	0.0021697	0.9794945
0.687	0.0927529	1585	1.0225847	761	1.4256648	0.0021635	0.9794317
0.688	0.0929114	1586	1.0226608	763	1.4235013	0.0021574	0.9793689
0.689	0.0930700	1588	1.0227371	764	1.4213439	0.0021514	0.9793059
0.690	0.0932288	1589	1.0228135	766	1.4191925	0.0021453	0.9792428
0.691	0.0933877	1590	1.0228901	768	1.4170472	0.0021393	0.9791796
0.692	0.0935467	1592	1.0229669	770	1.4149079	0.0021332	0.9791163
0.693	0.0937059	1593	1.0230439	772	1.4127747	0.0021273	0.9790529
0.694	0.0938652	1594	1.0231211	774	1.4106474	0.0021212	0.9789893
0.695	0.0940246	1595	1.0231985	775	1.4085262	0.0021154	0.9789257
0.696	0.0941841	1597	1.0232760	778	1.4064108	0.0021094	0.9788619
0.697	0.0943438	1598	1.0233538	779	1.4043014	0.0021036	0.9787981
0.698	0.0945036	1599	1.0234317	781	1.4021978	0.0020977	0.9787341
0.699	0.0946635	1601	1.0235098	783	1.4001001	0.0020918	0.9786700
0.700	0.0948236		1.0235881		1.3980083		0.9786058

SAG CALCULATING TABLE FOR TRANSMISSION LINES

= $\frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.700	0.0948236		1.0235881		1.3980083		0.9786058
0.701	0.0949838	1602	1.0236665	784	1.3959222	0.0020861	0.9785414
0.702	0.0951441	1603	1.0237452	787	1.3938419	0.0020803	0.9784770
0.703	0.0953046	1605	1.0238241	789	1.3917674	0.0020745	0.9784125
0.704	0.0954652	1606	1.0239032	791	1.3896987	0.0020687	0.9783478
0.705	0.0956259	1607	1.0239825	793	1.3876356	0.0020631	0.9782831
0.706	0.0957868	1609	1.0240619	794	1.3855782	0.0020574	0.9782182
0.707	0.0959478	1610	1.0241415	796	1.3835264	0.0020518	0.9781532
0.708	0.0961090	1612	1.0242213	798	1.3814803	0.0020461	0.9780880
0.709	0.0962703	1613	1.0243013	800	1.3794398	0.0020405	0.9780228
0.710	0.0964317	1614	1.0243816	803	1.3774050	0.0020348	0.9779575
0.711	0.0965932	1615	1.0244620	804	1.3753757	0.0020293	0.9778921
0.712	0.0967549	1617	1.0245426	806	1.3733519	0.0020238	0.9778265
0.713	0.0969167	1618	1.0246234	808	1.3713336	0.0020183	0.9777609
0.714	0.0970787	1620	1.0247044	810	1.3693208	0.0020128	0.9776951
0.715	0.0972408	1621	1.0247856	812	1.3673135	0.0020073	0.9776292
0.716	0.0974030	1622	1.0248669	813	1.3653117	0.0020018	0.9775632
0.717	0.0975654	1624	1.0249485	816	1.3633153	0.0019964	0.9774970
0.718	0.0977279	1625	1.0250303	818	1.3613243	0.0019910	0.9774308
0.719	0.0978905	1626	1.0251122	819	1.3593387	0.0019856	0.9773645
0.720	0.0980533	1628	1.0251944	822	1.3573584	0.0019803	0.9772980
0.721	0.0982162	1629	1.0252768	824	1.3553834	0.0019750	0.9772314
0.722	0.0983793	1631	1.0253594	826	1.3534138	0.0019696	0.9771648
0.723	0.0985425	1632	1.0254422	828	1.3514494	0.0019644	0.9770979
0.724	0.0987059	1634	1.0255251	829	1.3494903	0.0019591	0.9770310
0.725	0.0988694	1635	1.0256082	831	1.3475365	0.0019538	0.9769639
0.726	0.0990331	1637	1.0256916	834	1.3455879	0.0019486	0.9768968
0.727	0.0991969	1638	1.0257752	836	1.3436445	0.0019434	0.9768295
0.728	0.0993608	1639	1.0258590	838	1.3417063	0.0019382	0.9767622
0.729	0.0995249	1641	1.0259430	840	1.3397732	0.0019331	0.9766947
0.730	0.0996891	1642	1.0260272	842	1.3378453	0.0019279	0.9766271
0.731	0.0998535	1644	1.0261115	843	1.3359225	0.0019228	0.9765593
0.732	0.1000180	1645	1.0261961	846	1.3340048	0.0019177	0.9764915
0.733	0.1001826	1646	1.0262809	848	1.3320921	0.0019127	0.9764235
0.734	0.1003474	1648	1.0263659	850	1.3301845	0.0019076	0.9763554
0.735	0.1005124	1650	1.0264511	852	1.3282819	0.0019026	0.9762872
0.736	0.1006775	1651	1.0265365	854	1.3263844	0.0018975	0.9762189
0.737	0.1008428	1653	1.0266221	856	1.3244919	0.0018925	0.9761505
0.738	0.1010082	1654	1.0267080	859	1.3226043	0.0018876	0.9760820
0.739	0.1011738	1656	1.0267940	860	1.3207217	0.0018826	0.9760133
0.740	0.1013395	1657	1.0268803	863	1.3188440	0.0018777	0.9759445
0.741	0.1015053	1658	1.0269667	864	1.3169712	0.0018728	0.9758756
0.742	0.1016713	1660	1.0270534	867	1.3151033	0.0018679	0.9758066
0.743	0.1018375	1662	1.0271403	869	1.3132403	0.0018630	0.9757375
0.744	0.1020038	1663	1.0272274	871	1.3113821	0.0018582	0.9756683
0.745	0.1021703	1665	1.0273147	873	1.3095287	0.0018534	0.9755989
0.746	0.1023369	1666	1.0274022	875	1.3076802	0.0018485	0.9755294
0.747	0.1025037	1668	1.0274899	877	1.3058364	0.0018438	0.9754598
0.748	0.1026706	1669	1.0275779	880	1.3039975	0.0018389	0.9753901
0.749	0.1028377	1671	1.0276660	881	1.3021633	0.0018342	0.9753203
0.750	0.1030049	1672	1.0277544	884	1.3003338	0.0018295	0.9752504

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.750	0.1030049	1674	1.0277544	886	1.3003338	0.0018248	0.9752504
0.751	0.1031723	1676	1.0278430	888	1.2985090	0.0018200	0.9751803
0.752	0.1033399	1677	1.0279318	890	1.2966890	0.0018154	0.9751101
0.753	0.1035076	1679	1.0280208	893	1.2948736	0.0018107	0.9750398
0.754	0.1036755	1680	1.0281101	894	1.2930629	0.0018061	0.9749694
0.755	0.1038435	1682	1.0281995	897	1.2912568	0.0018015	0.9748989
0.756	0.1040117	1683	1.0282892	899	1.2894553	0.0017969	0.9748282
0.757	0.1041800	1685	1.0283791	901	1.2876584	0.0017923	0.9747574
0.758	0.1043485	1687	1.0284692	903	1.2858661	0.0017877	0.9746865
0.759	0.1045172	1688	1.0285595	906	1.2840784	0.0017832	0.9746155
0.760	0.1046860	1690	1.0286501	908	1.2822952	0.0017786	0.9745444
0.761	0.1048550	1691	1.0287409	910	1.2805166	0.0017741	0.9744731
0.762	0.1050241	1693	1.0288319	912	1.2787425	0.0017696	0.9744018
0.763	0.1051934	1695	1.0289231	915	1.2769729	0.0017652	0.9743303
0.764	0.1053629	1696	1.0290146	917	1.2752077	0.0017607	0.9742587
0.765	0.1055325	1698	1.0291063	919	1.2734470	0.0017563	0.9741870
0.766	0.1057023	1700	1.0291982	921	1.2716907	0.0017519	0.9741151
0.767	0.1058723	1701	1.0292903	923	1.2699388	0.0017474	0.9740431
0.768	0.1060424	1703	1.0293826	926	1.2681914	0.0017430	0.9739710
0.769	0.1062127	1705	1.0294752	928	1.2664484	0.0017387	0.9738988
0.770	0.1063832	1706	1.0295680	930	1.2647097	0.0017343	0.9738265
0.771	0.1065538	1708	1.0296610	933	1.2629754	0.0017300	0.9737540
0.772	0.1067246	1710	1.0297543	935	1.2612454	0.0017256	0.9736815
0.773	0.1068956	1711	1.0298478	937	1.2595198	0.0017214	0.9736088
0.774	0.1070667	1713	1.0299415	940	1.2577984	0.0017171	0.9735360
0.775	0.1072380	1715	1.0300355	942	1.2560813	0.0017128	0.9734630
0.776	0.1074095	1717	1.0301297	944	1.2543685	0.0017086	0.9733900
0.777	0.1075812	1718	1.0302241	946	1.2526599	0.0017043	0.9733168
0.778	0.1077530	1720	1.0303187	949	1.2509556	0.0017001	0.9732435
0.779	0.1079250	1721	1.0304136	951	1.2492555	0.0016959	0.9731700
0.780	0.1080971	1724	1.0305087	954	1.2475596	0.0016917	0.9730965
0.781	0.1082695	1725	1.0306041	956	1.2458679	0.0016876	0.9730228
0.782	0.1084420	1727	1.0306997	959	1.2441803	0.0016834	0.9729490
0.783	0.1086147	1728	1.0307956	960	1.2424969	0.0016792	0.9728751
0.784	0.1087875	1730	1.0308916	963	1.2408177	0.0016751	0.9728011
0.785	0.1089605	1732	1.0309879	966	1.2391426	0.0016710	0.9727270
0.786	0.1091337	1734	1.0310845	968	1.2374716	0.0016669	0.9726527
0.787	0.1093071	1736	1.0311813	970	1.2358047	0.0016629	0.9725783
0.788	0.1094807	1737	1.0312783	972	1.2341418	0.0016588	0.9725037
0.789	0.1096544	1739	1.0313755	975	1.2324830	0.0016548	0.9724291
0.790	0.1098283	1741	1.0314730	978	1.2308282	0.0016507	0.9723543
0.791	0.1100024	1743	1.0315708	980	1.2291775	0.0016467	0.9722794
0.792	0.1101767	1745	1.0316688	982	1.2275308	0.0016427	0.9722044
0.793	0.1103512	1746	1.0317670	985	1.2258881	0.0016387	0.9721293
0.794	0.1105258	1749	1.0318655	987	1.2242494	0.0016348	0.9720540
0.795	0.1107007	1750	1.0319642	990	1.2226146	0.0016308	0.9719786
0.796	0.1108757	1752	1.0320632	992	1.2209838	0.0016269	0.9719031
0.797	0.1110509	1753	1.0321624	995	1.2193569	0.0016229	0.9718274
0.798	0.1112262	1756	1.0322619	997	1.2177340	0.0016190	0.9717517
0.799	0.1114018	1757	1.0323616	1000	1.2161150	0.0016152	0.9716759
0.800	0.1115775		1.0324616		1.2144998		0.9715998

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$= \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.800	0.1115775		1.0324616		1.2144998		0.9715998
0.801	0.1117535	1760	1.0325618	1002	1.2128884	16114	0.9715236
0.802	0.1119296	1761	1.0326623	1005	1.2112810	16074	0.9714474
0.803	0.1121059	1763	1.0327630	1007	1.2096774	16036	0.9713710
0.804	0.1122824	1765	1.0328640	1010	1.2080777	15997	0.9712945
0.805	0.1124590	1766	1.0329652	1012	1.2064818	15959	0.9712179
0.806	0.1126359	1769	1.0330667	1015	1.2048897	15921	0.9711411
0.807	0.1128129	1770	1.0331684	1017	1.2033014	15883	0.9710642
0.808	0.1129902	1773	1.0332704	1020	1.2017168	15846	0.9709872
0.809	0.1131676	1774	1.0333726	1022	1.2001360	15808	0.9709100
0.810	0.1133453	1777	1.0334751	1025	1.1985589	15771	0.9708327
0.811	0.1135231	1778	1.0335779	1028	1.1969856	15733	0.9707553
0.812	0.1137011	1780	1.0336809	1030	1.1954160	15696	0.9706778
0.813	0.1138793	1782	1.0337842	1033	1.1938501	15659	0.9706002
0.814	0.1140577	1784	1.0338877	1035	1.1922879	15622	0.9705224
0.815	0.1142363	1786	1.0339915	1038	1.1907294	15585	0.9704445
0.816	0.1144151	1788	1.0340956	1041	1.1891746	15548	0.9703664
0.817	0.1145941	1790	1.0341999	1043	1.1876234	15512	0.9702883
0.818	0.1147733	1792	1.0343045	1046	1.1860758	15476	0.9702100
0.819	0.1149527	1794	1.0344094	1049	1.1845318	15440	0.9701316
0.820	0.1151323	1796	1.0345145	1051	1.1829915	15403	0.9700530
0.821	0.1153121	1798	1.0346199	1054	1.1814547	15368	0.9699743
0.822	0.1154921	1800	1.0347256	1057	1.1799216	15331	0.9698955
0.823	0.1156723	1802	1.0348315	1059	1.1783920	15296	0.9698166
0.824	0.1158527	1804	1.0349377	1062	1.1768659	15261	0.9697375
0.825	0.1160333	1806	1.0350442	1065	1.1753434	15225	0.9696583
0.826	0.1162141	1808	1.0351509	1067	1.1738245	15189	0.9695790
0.827	0.1163951	1810	1.0352579	1070	1.1723091	15154	0.9694996
0.828	0.1165763	1812	1.0353652	1073	1.1707971	15120	0.9694200
0.829	0.1167577	1814	1.0354727	1075	1.1692887	15084	0.9693403
0.830	0.1169393	1816	1.0355805	1078	1.1677837	15050	0.9692605
0.831	0.1171211	1818	1.0356886	1081	1.1662822	15015	0.9691805
0.832	0.1173032	1821	1.0357970	1084	1.1647841	14981	0.9691004
0.833	0.1174854	1822	1.0359057	1087	1.1632895	14946	0.9690202
0.834	0.1176679	1825	1.0360146	1089	1.1617983	14912	0.9689398
0.835	0.1178506	1827	1.0361239	1093	1.1603105	14878	0.9688593
0.836	0.1180335	1829	1.0362334	1095	1.1588262	14843	0.9687787
0.837	0.1182166	1831	1.0363432	1098	1.1573452	14810	0.9686980
0.838	0.1183999	1833	1.0364532	1100	1.1558676	14776	0.9686170
0.839	0.1185834	1835	1.0365636	1104	1.1543934	14742	0.9685361
0.840	0.1187672	1838	1.0366742	1106	1.1529225	14709	0.9684549
0.841	0.1189511	1839	1.0367851	1109	1.1514549	14676	0.9683736
0.842	0.1191353	1842	1.0368963	1112	1.1499907	14642	0.9682922
0.843	0.1193197	1844	1.0370078	1115	1.1485298	14609	0.9682107
0.844	0.1195043	1846	1.0371195	1117	1.1470722	14576	0.9681289
0.845	0.1196891	1848	1.0372316	1121	1.1456179	14543	0.9680472
0.846	0.1198742	1851	1.0373439	1123	1.1441669	14510	0.9679652
0.847	0.1200594	1852	1.0374566	1127	1.1427192	14477	0.9678831
0.848	0.1202449	1855	1.0375695	1129	1.1412747	14445	0.9678009
0.849	0.1204306	1857	1.0376828	1133	1.1398335	14412	0.9677186
0.850	0.1206166	1860	1.0377963	1135	1.1383954	14381	0.9676361

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.850	0.1206166		1.0377963		1.1383954		0.9676361
0.851	0.1208027	1861	1.0379101	1138	1.1369606	14348	0.9675535
0.852	0.1209891	1864	1.0380242	1141	1.1355291	14315	0.9674708
0.853	0.1211757	1866	1.0381387	1145	1.1341007	14284	0.9673879
0.854	0.1213626	1869	1.0382534	1147	1.1326755	14252	0.9673049
0.855	0.1215496	1870	1.0383684	1150	1.1312535	14220	0.9672218
0.856	0.1217369	1873	1.0384837	1153	1.1298346	14189	0.9671385
0.857	0.1219244	1875	1.0385993	1156	1.1284189	14157	0.9670550
0.858	0.1221121	1877	1.0387152	1159	1.1270064	14125	0.9669715
0.859	0.1223001	1880	1.0388314	1162	1.1255970	14094	0.9668878
0.860	0.1224883	1882	1.0389479	1165	1.1241907	14063	0.9668040
0.861	0.1226767	1884	1.0390647	1168	1.1227875	14032	0.9667200
0.862	0.1228654	1887	1.0391819	1172	1.1213874	14001	0.9666360
0.863	0.1230543	1889	1.0392994	1175	1.1199905	13969	0.9665518
0.864	0.1232435	1892	1.0394171	1177	1.1185965	13940	0.9664674
0.865	0.1234329	1894	1.0395352	1181	1.1172057	13908	0.9663829
0.866	0.1236225	1896	1.0396535	1183	1.1158178	13879	0.9662982
0.867	0.1238124	1899	1.0397722	1187	1.1144331	13847	0.9662135
0.868	0.1240025	1901	1.0398912	1190	1.1130514	13817	0.9661286
0.869	0.1241928	1903	1.0400106	1194	1.1116727	13787	0.9660435
0.870	0.1243834	1906	1.0401302	1196	1.1102969	13758	0.9659583
0.871	0.1245742	1908	1.0402501	1199	1.1089242	13727	0.9658730
0.872	0.1247653	1911	1.0403704	1203	1.1075545	13697	0.9657875
0.873	0.1249566	1913	1.0404910	1206	1.1061878	13667	0.9657019
0.874	0.1251482	1916	1.0406119	1209	1.1048240	13638	0.9656162
0.875	0.1253400	1918	1.0407331	1212	1.1034632	13608	0.9655303
0.876	0.1255321	1921	1.0408546	1215	1.1021053	13579	0.9654442
0.877	0.1257244	1923	1.0409765	1219	1.1007504	13549	0.9653581
0.878	0.1259170	1926	1.0410987	1222	1.0993984	13520	0.9652718
0.879	0.1261098	1928	1.0412212	1225	1.0980493	13491	0.9651853
0.880	0.1263028	1930	1.0413441	1229	1.0967032	13461	0.9650988
0.881	0.1264961	1933	1.0414673	1232	1.0953599	13433	0.9650121
0.882	0.1266896	1935	1.0415908	1235	1.0940195	13404	0.9649252
0.883	0.1268834	1938	1.0417146	1238	1.0926820	13375	0.9648382
0.884	0.1270775	1941	1.0418388	1242	1.0913474	13346	0.9647511
0.885	0.1272718	1943	1.0419633	1245	1.0900156	13318	0.9646638
0.886	0.1274664	1946	1.0420881	1248	1.0886867	13289	0.9645764
0.887	0.1276613	1949	1.0422133	1252	1.0873606	13261	0.9644889
0.888	0.1278564	1951	1.0423388	1255	1.0860374	13232	0.9644012
0.889	0.1280518	1954	1.0424647	1259	1.0847169	13205	0.9643133
0.890	0.1282474	1956	1.0425909	1262	1.0833993	13176	0.9642254
0.891	0.1284433	1959	1.0427174	1265	1.0820845	13148	0.9641373
0.892	0.1286394	1961	1.0428443	1269	1.0807742	13121	0.9640490
0.893	0.1288358	1964	1.0429715	1272	1.0794631	13093	0.9693966
0.894	0.1290325	1967	1.0430991	1276	1.0781566	13065	0.9638720
0.895	0.1292295	1970	1.0432270	1279	1.0768528	13038	0.9637833
0.896	0.1294267	1972	1.0433553	1283	1.0755519	13009	0.9636945
0.897	0.1296242	1975	1.0434839	1286	1.0742536	12983	0.9636055
0.898	0.1298220	1978	1.0436129	1290	1.0729581	12955	0.9635164
0.899	0.1300200	1980	1.0437422	1293	1.0716653	12928	0.9634271
0.900	0.1302183	1983	1.0438719	1297	1.0703752	12901	0.9633377

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
0.900	0.1302183	1985	1.0438719	1300	1.0703752	12873	0.9633377
0.901	0.1304168	1989	1.0440019	1304	1.0690879	12847	0.9632482
0.902	0.1306157	1991	1.0441323	1307	1.0678032	12820	0.9631585
0.903	0.1308148	1994	1.0442630	1311	1.0665212	12793	0.9630686
0.904	0.1310142	1997	1.0443941	1315	1.0652419	12767	0.9629786
0.905	0.1312139	2000	1.0445256	1318	1.0639652	12740	0.9628885
0.906	0.1314139	2002	1.0446574	1322	1.0626912	12713	0.9627982
0.907	0.1316141	2006	1.0447896	1326	1.0614199	12688	0.9627078
0.908	0.1318147	2008	1.0449222	1329	1.0601511	12661	0.9626172
0.909	0.1320155	2011	1.0450551	1333	1.0588850	12634	0.9625265
0.910	0.1322166	2013	1.0451884	1337	1.0576216	12608	0.9624356
0.911	0.1324179	2017	1.0453221	1340	1.0563608	12583	0.9623447
0.912	0.1326196	2019	1.0454561	1344	1.0551025	12556	0.9622535
0.913	0.1328215	2023	1.0455905	1348	1.0538469	12531	0.9621622
0.914	0.1330238	2025	1.0457253	1351	1.0525938	12505	0.9620708
0.915	0.1332263	2029	1.0458604	1355	1.0513433	12479	0.9619792
0.916	0.1334292	2031	1.0459959	1359	1.0500954	12454	0.9618874
0.917	0.1336323	2035	1.0461318	1363	1.0488500	12428	0.9617955
0.918	0.1338358	2037	1.0462681	1367	1.0476072	12403	0.9617034
0.919	0.1340395	2040	1.0464048	1370	1.0463669	12377	0.9616112
0.920	0.1342435	2043	1.0465418	1375	1.0451292	12352	0.9615189
0.921	0.1344478	2046	1.0466793	1378	1.0438940	12327	0.9614264
0.922	0.1346524	2049	1.0468171	1382	1.0426613	12301	0.9613337
0.923	0.1348573	2053	1.0469553	1386	1.0414312	12277	0.9612410
0.924	0.1350626	2055	1.0470939	1390	1.0402035	12252	0.9611480
0.925	0.1352681	2059	1.0472329	1394	1.0389783	12227	0.9610549
0.926	0.1354740	2061	1.0473723	1398	1.0377556	12202	0.9609617
0.927	0.1356801	2065	1.0475121	1402	1.0365354	12178	0.9608683
0.928	0.1358866	2067	1.0476523	1406	1.0353176	12152	0.9607748
0.929	0.1360933	2071	1.0477929	1409	1.0341024	12129	0.9606811
0.930	0.1363004	2074	1.0479338	1414	1.0328895	12104	0.9605872
0.931	0.1365078	2077	1.0480752	1418	1.0316791	12080	0.9604932
0.932	0.1367155	2080	1.0482170	1422	1.0304711	12055	0.9603991
0.933	0.1369235	2083	1.0483592	1426	1.0292656	12031	0.9603048
0.934	0.1371318	2086	1.0485018	1430	1.0280625	12007	0.9602103
0.935	0.1373404	2090	1.0486448	1434	1.0268618	11984	0.9601158
0.936	0.1375494	2093	1.0487882	1438	1.0256634	11959	0.9600210
0.937	0.1377587	2096	1.0489320	1442	1.0244675	11936	0.9599261
0.938	0.1379683	2099	1.0490762	1447	1.0232739	11911	0.9598310
0.939	0.1381782	2103	1.0492209	1450	1.0220828	11888	0.9597358
0.940	0.1383885	2106	1.0493659	1455	1.0208940	11864	0.9596404
0.941	0.1385991	2109	1.0495114	1459	1.0197076	11841	0.9595449
0.942	0.1388100	2112	1.0496573	1464	1.0185235	11817	0.9594491
0.943	0.1390212	2116	1.0498037	1467	1.0173418	11794	0.9593533
0.944	0.1392328	2119	1.0499504	1472	1.0161624	11771	0.9592573
0.945	0.1394447	2122	1.0500976	1476	1.0149853	11747	0.9591611
0.946	0.1396569	2126	1.0502452	1481	1.0138106	11724	0.9590648
0.947	0.1398695	2129	1.0503933	1484	1.0126382	11701	0.9589684
0.948	0.1400824	2133	1.0505417	1490	1.0114681	11678	0.9588718
0.949	0.1402957	2136	1.0506907	1493	1.0103003	11655	0.9587750
0.950	0.1405093		1.0508400		1.0091348		0.9586781

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch x
0.950	0.1405093	2139	1.0508400	1498	1.0091348	11632	0.9586781
0.951	0.1407232	2143	1.0509898	1502	1.0079716	11610	0.9585810
0.952	0.1409375	2146	1.0511400	1507	1.0068106	11587	0.9584837
0.953	0.1411521	2150	1.0512907	1511	1.0056519	11563	0.9583863
0.954	0.1413671	2153	1.0514418	1515	1.0044956	11542	0.9582888
0.955	0.1415824	2157	1.0515933	1520	1.0033414	11519	0.9581911
0.956	0.1417981	2160	1.0517453	1525	1.0021895	11497	0.9580932
0.957	0.1420141	2164	1.0518978	1529	1.0010398	11474	0.9579951
0.958	0.1422305	2167	1.0520507	1533	0.9998924	11452	0.9578969
0.959	0.1424472	2171	1.0522040	1538	0.9987472	11430	0.9577986
0.960	0.1426643	2175	1.0523578	1543	0.9976042	11408	0.9577000
0.961	0.1428818	2178	1.0525121	1547	0.9964634	11386	0.9576013
0.962	0.1430996	2182	1.0526668	1552	0.9953248	11363	0.9575025
0.963	0.1433178	2185	1.0528220	1557	0.9941885	11342	0.9574035
0.964	0.1435363	2189	1.0529777	1561	0.9930543	11320	0.9573043
0.965	0.1437552	2193	1.0531338	1566	0.9919223	11298	0.9572050
0.966	0.1439745	2196	1.0532904	1571	0.9907925	11277	0.9571055
0.967	0.1441941	2200	1.0534475	1575	0.9896648	11255	0.9570059
0.968	0.1444141	2204	1.0536050	1580	0.9885393	11233	0.9569060
0.969	0.1446345	2207	1.0537630	1585	0.9874160	11212	0.9568061
0.970	0.1448552	2211	1.0539215	1590	0.9862948	11191	0.9567060
0.971	0.1450763	2216	1.0540805	1594	0.9851757	11169	0.9566056
0.972	0.1452979	2219	1.0542399	1600	0.9840588	11148	0.9565052
0.973	0.1455198	2223	1.0543999	1604	0.9829440	11126	0.9564046
0.974	0.1457421	2226	1.0545603	1609	0.9818314	11106	0.9563038
0.975	0.1459647	2231	1.0547212	1614	0.9807208	11084	0.9562028
0.976	0.1461878	2234	1.0548826	1619	0.9796124	11064	0.9561017
0.977	0.1464112	2239	1.0550445	1624	0.9785060	11043	0.9560004
0.978	0.1466351	2242	1.0552069	1629	0.9774017	11021	0.9558989
0.979	0.1468593	2246	1.0553698	1634	0.9762996	11001	0.9557973
0.980	0.1470839	2250	1.0555332	1639	0.9751995	10980	0.9556955
0.981	0.1473089	2254	1.0556971	1644	0.9741015	10960	0.9555935
0.982	0.1475343	2258	1.0558615	1649	0.9730055	10939	0.9554914
0.983	0.1477601	2262	1.0560264	1654	0.9719116	10919	0.9553891
0.984	0.1479863	2266	1.0561918	1659	0.9708197	10898	0.9552866
0.985	0.1482129	2270	1.0563577	1665	0.9697299	10877	0.9551840
0.986	0.1484399	2274	1.0565242	1670	0.9686422	10858	0.9550812
0.987	0.1486673	2279	1.0566912	1675	0.9675564	10836	0.9549782
0.988	0.1488952	2282	1.0568587	1680	0.9664728	10817	0.9548751
0.989	0.1491234	2287	1.0570267	1686	0.9653911	10796	0.9547718
0.990	0.1493521	2291	1.0571953	1691	0.9643115	10776	0.9546684
0.991	0.1495812	2295	1.0573644	1696	0.9632339	10757	0.9545648
0.992	0.1498107	2299	1.0575340	1701	0.9621582	10737	0.9544609
0.993	0.1500406	2304	1.0577041	1707	0.9610845	10717	0.9543569
0.994	0.1502710	2308	1.0578748	1712	0.9600128	10697	0.9542527
0.995	0.1505018	2312	1.0580460	1718	0.9589431	10677	0.9541484
0.996	0.1507330	2316	1.0582178	1723	0.9578754	10658	0.9540439
0.997	0.1509646	2321	1.0583901	1729	0.9568096	10638	0.9539392
0.998	0.1511967	2325	1.0585630	1734	0.9557458	10618	0.9538343
0.999	0.1514292	2329	1.0587364	1739	0.9546840	10599	0.9537293
1.000	0.1516621		1.0589103		0.9536241		0.9536241

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
1.000	0.1516621	2334	1.0589103	1745	0.9536241	10579	0.9536241
1.001	0.1518955	2338	1.0590848	1751	0.9525662	10560	0.9535187
1.002	0.1521293	2342	1.0592599	1756	0.9515102	10541	0.9534132
1.003	0.1523635	2347	1.0594355	1762	0.9504561	10521	0.9533075
1.004	0.1525982	2351	1.0596117	1768	0.9494040	10503	0.9532016
1.005	0.1528333	2356	1.0597885	1773	0.9483537	10483	0.9530955
1.006	0.1530689	2361	1.0599658	1779	0.9473054	10464	0.9529892
1.007	0.1533050	2365	1.0601437	1785	0.9462590	10445	0.9528828
1.008	0.1535415	2369	1.0603222	1791	0.9452145	10426	0.9527762
1.009	0.1537784	2374	1.0605013	1796	0.9441719	10407	0.9526694
1.010	0.1540158	2379	1.0606809	1803	0.9431312	10388	0.9525625
1.011	0.1542537	2383	1.0608612	1808	0.9420924	10370	0.9524554
1.012	0.1544920	2389	1.0610420	1814	0.9410554	10351	0.9523480
1.013	0.1547309	2393	1.0612234	1821	0.9400203	10333	0.9522405
1.014	0.1549702	2398	1.0614055	1826	0.9389870	10314	0.9521328
1.015	0.1552100	2402	1.0615881	1832	0.9379556	10295	0.9520249
1.016	0.1554502	2407	1.0617713	1838	0.9369261	10277	0.9519169
1.017	0.1556909	2412	1.0619551	1845	0.9358984	10258	0.9518087
1.018	0.1559321	2417	1.0621396	1850	0.9348726	10240	0.9517003
1.019	0.1561738	2422	1.0623246	1857	0.9338486	10222	0.9515917
1.020	0.1564160	2427	1.0625103	1863	0.9328264	10203	0.9514829
1.021	0.1566587	2431	1.0626966	1869	0.9318061	10185	0.9513740
1.022	0.1569018	2436	1.0628835	1875	0.9307876	10167	0.9512649
1.023	0.1571454	2442	1.0630710	1882	0.9297709	10149	0.9511556
1.024	0.1573896	2446	1.0632592	1888	0.9287560	10131	0.9510461
1.025	0.1576342	2452	1.0634480	1895	0.9277429	10113	0.9509365
1.026	0.1578794	2456	1.0636375	1901	0.9267316	10095	0.9508266
1.027	0.1581250	2462	1.0638276	1907	0.9257221	10078	0.9507166
1.028	0.1583712	2467	1.0640183	1913	0.9247143	10059	0.9506063
1.029	0.1586179	2472	1.0642096	1920	0.9237084	10042	0.9504959
1.030	0.1588651	2477	1.0644016	1927	0.9227042	10024	0.9503853
1.031	0.1591128	2482	1.0645943	1933	0.9217018	10007	0.9502745
1.032	0.1593610	2488	1.0647876	1940	0.9207011	9989	0.9501635
1.033	0.1596098	2493	1.0649816	1947	0.9197022	9972	0.9500523
1.034	0.1598591	2498	1.0651763	1953	0.9187050	9954	0.9499410
1.035	0.1601089	2503	1.0653716	1960	0.9177096	9936	0.9498295
1.036	0.1603592	2508	1.0655676	1967	0.9167160	9919	0.9497177
1.037	0.1606100	2514	1.0657643	1973	0.9157241	9902	0.9496059
1.038	0.1608614	2519	1.0659616	1981	0.9147339	9885	0.9494937
1.039	0.1611133	2525	1.0661597	1987	0.9137454	9868	0.9493815
1.040	0.1613658	2531	1.0663584	1994	0.9127586	9851	0.9492690
1.041	0.1616189	2536	1.0665578	2001	0.9117735	9833	0.9491563
1.042	0.1618725	2542	1.0667579	2009	0.9107902	9816	0.9490434
1.043	0.1621267	2547	1.0669588	2015	0.9098086	9800	0.9489303
1.044	0.1623814	2553	1.0671603	2023	0.9088286	9783	0.9488171
1.045	0.1626367	2559	1.0673626	2029	0.9078503	9766	0.9487036
1.046	0.1628926	2564	1.0675655	2037	0.9068737	9749	0.9485899
1.047	0.1631490	2570	1.0677692	2044	0.9058988	9732	0.9484761
1.048	0.1634060	2576	1.0679736	2051	0.9049256	9716	0.9483621
1.049	0.1636636	2581	1.0681787	2059	0.9039540	9698	0.9482478
1.050	0.1639217		1.0683846		0.9029842		0.9481334

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
1.050	0.1639217	2587	1.0683846	2066	0.9029842	9682	0.9481334
1.051	0.1641804	2593	1.0685912	2074	0.9020160	9666	0.9480188
1.052	0.1644397	2599	1.0687986	2081	0.9010494	9649	0.9479040
1.053	0.1646996	2605	1.0690067	2088	0.9000845	9633	0.9477890
1.054	0.1649601	2611	1.0692155	2096	0.8991212	9616	0.9476737
1.055	0.1652212	2617	1.0694251	2103	0.8981596	9600	0.9475584
1.056	0.1654829	2623	1.0696354	2111	0.8971996	9584	0.9474427
1.057	0.1657452	2629	1.0698465	2119	0.8962412	9567	0.9473269
1.058	0.1660081	2635	1.0700584	2127	0.8952845	9552	0.9472109
1.059	0.1662716	2642	1.0702711	2134	0.8943293	9535	0.9470947
1.060	0.1665358	2647	1.0704845	2142	0.8933758	9520	0.9469783
1.061	0.1668005	2654	1.0706987	2150	0.8924238	9503	0.9468617
1.062	0.1670659	2660	1.0709137	2158	0.8914735	9487	0.9467449
1.063	0.1673319	2666	1.0711295	2166	0.8905248	9471	0.9466278
1.064	0.1675985	2673	1.0713461	2174	0.8895777	9455	0.9465107
1.065	0.1678658	2679	1.0715635	2182	0.8886322	9440	0.9463933
1.066	0.1681337	2686	1.0717817	2190	0.8876882	9424	0.9462756
1.067	0.1684023	2692	1.0720007	2198	0.8867458	9408	0.9461578
1.068	0.1686715	2699	1.0722205	2207	0.8858050	9393	0.9460397
1.069	0.1689414	2705	1.0724412	2215	0.8848657	9377	0.9459214
1.070	0.1692119	2712	1.0726627	2223	0.8839280	9361	0.9458030
1.071	0.1694831	2719	1.0728850	2232	0.8829919	9346	0.9456843
1.072	0.1697550	2725	1.0731082	2240	0.8820573	9330	0.9455654
1.073	0.1700275	2732	1.0733322	2248	0.8811243	9315	0.9454463
1.074	0.1703007	2739	1.0735570	2257	0.8801928	9300	0.9453270
1.075	0.1705746	2746	1.0737827	2266	0.8792628	9284	0.9452075
1.076	0.1708492	2753	1.0740093	2275	0.8783344	9269	0.9450878
1.077	0.1711245	2759	1.0742368	2283	0.8774075	9254	0.9449679
1.078	0.1714004	2767	1.0744651	2292	0.8764821	9238	0.9448477
1.079	0.1716771	2773	1.0746943	2301	0.8755583	9223	0.9447274
1.080	0.1719544	2781	1.0749244	2310	0.8746360	9208	0.9446068
1.081	0.1722325	2787	1.0751554	2319	0.8737152	9194	0.9444861
1.082	0.1725112	2794	1.0753873	2328	0.8737958	9177	0.9443651
1.083	0.1727906	2802	1.0756201	2337	0.8718781	9164	0.9442439
1.084	0.1730708	2809	1.0758538	2346	0.8709617	9148	0.9441225
1.085	0.1733517	2817	1.0760884	2356	0.8700469	9134	0.9440009
1.086	0.1736334	2824	1.0763240	2364	0.8691335	9118	0.9438790
1.087	0.1739158	2832	1.0765604	2374	0.8682217	9105	0.9437570
1.088	0.1741990	2839	1.0767978	2383	0.8673112	9089	0.9436347
1.089	0.1744829	2846	1.0770361	2393	0.8664023	9074	0.9435121
1.090	0.1747675	2854	1.0772754	2403	0.8654949	9060	0.9433894
1.091	0.1750529	2861	1.0775157	2412	0.8645889	9045	0.9432665
1.092	0.1753390	2869	1.0777569	2422	0.8636844	9031	0.9431434
1.093	0.1756259	2877	1.0779991	2432	0.8627813	9016	0.9430200
1.094	0.1759136	2885	1.0782423	2442	0.8618797	9002	0.9428964
1.095	0.1762021	2893	1.0784865	2451	0.8609795	8987	0.9427726
1.096	0.1764914	2901	1.0787316	2462	0.8600808	8974	0.9426485
1.097	0.1767815	2909	1.0789778	2471	0.8591834	8959	0.9425242
1.098	0.1770724	2917	1.0792249	2482	0.8582875	8944	0.9423997
1.099	0.1773641	2925	1.0794731	2491	0.8573931	8931	0.9422750
1.100	0.1776566		1.0797222		0.8565000		0.9421500

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
1.100	0.1776566		1.0797222		0.8565000		0.9421500
1.101	0.1779499	2933	1.0799724	2502	0.8556084	8916	0.9420248
1.102	0.1782440	2941	1.0802236	2512	0.8547181	8903	0.9418994
1.103	0.1785389	2949	1.0804759	2523	0.8538294	8887	0.9417738
1.104	0.1788347	2958	1.0807293	2534	0.8529419	8875	0.9416479
1.105	0.1791313	2966	1.0809837	2544	0.8520559	8860	0.9415218
1.106	0.1794287	2974	1.0812392	2555	0.8511714	8845	0.9413955
1.107	0.1797270	2983	1.0814958	2566	0.8502882	8832	0.9412690
1.108	0.1800262	2992	1.0817534	2576	0.8494063	8819	0.9411422
1.109	0.1803262	3000	1.0820121	2587	0.8485259	8804	0.9410152
1.110	0.1806271	3009	1.0822719	2598	0.8476468	8791	0.9408879
1.111	0.1809289	3018	1.0825329	2610	0.8467691	8777	0.9407604
1.112	0.1812316	3027	1.0827949	2620	0.8458927	8764	0.9406327
1.113	0.1815352	3036	1.0830581	2632	0.8450177	8750	0.9405047
1.114	0.1818396	3044	1.0833224	2643	0.8441441	8736	0.9403765
1.115	0.1821449	3053	1.0835878	2654	0.8432718	8723	0.9402481
1.116	0.1824512	3063	1.0838544	2666	0.8424009	8709	0.9401194
1.117	0.1827584	3072	1.0841222	2678	0.8415313	8696	0.9399905
1.118	0.1830665	3081	1.0843911	2689	0.8406631	8682	0.9398614
1.119	0.1833755	3090	1.0846612	2701	0.8397962	8669	0.9397320
1.120	0.1836855	3100	1.0849325	2713	0.8389307	8655	0.9396024
1.121	0.1839964	3109	1.0852050	2725	0.8380665	8642	0.9394725
1.122	0.1843083	3119	1.0854787	2737	0.8372036	8629	0.9393424
1.123	0.1846212	3129	1.0857536	2749	0.8363419	8617	0.9392120
1.124	0.1849350	3138	1.0860298	2762	0.8354817	8602	0.9390814
1.125	0.1852498	3148	1.0863072	2774	0.8346227	8590	0.9389505
1.126	0.1855657	3159	1.0865859	2787	0.8337651	8576	0.9388195
1.127	0.1858826	3169	1.0868658	2799	0.8329087	8564	0.9386881
1.128	0.1862004	3178	1.0871470	2812	0.8320536	8551	0.9385565
1.129	0.1865193	3189	1.0874295	2825	0.8311998	8538	0.9384246
1.130	0.1868392	3199	1.0877132	2837	0.8303473	8525	0.9382925
1.131	0.1871601	3209	1.0879982	2850	0.8294961	8512	0.9381601
1.132	0.1874820	3219	1.0882846	2864	0.8286462	8499	0.9380275
1.133	0.1878050	3230	1.0885723	2877	0.8277975	8487	0.9378946
1.134	0.1881290	3240	1.0888613	2890	0.8269502	8473	0.9377615
1.135	0.1884541	3251	1.0891517	2904	0.8261041	8461	0.9376281
1.136	0.1887803	3262	1.0894434	2917	0.8252592	8449	0.9374945
1.137	0.1891076	3273	1.0897365	2931	0.8244156	8436	0.9373606
1.138	0.1894359	3283	1.0900310	2945	0.8235733	8423	0.9372265
1.139	0.1897654	3295	1.0903269	2959	0.8227323	8410	0.9370921
1.140	0.1900960	3306	1.0906242	2973	0.8218924	8399	0.9369574
1.141	0.1904277	3317	1.0909229	2987	0.8210539	8385	0.9368225
1.142	0.1907606	3329	1.0912231	3002	0.8202165	8374	0.9366872
1.143	0.1910946	3340	1.0915247	3016	0.8193804	8361	0.9365518
1.144	0.1914297	3351	1.0918278	3031	0.8185455	8349	0.9364161
1.145	0.1917660	3363	1.0921323	3045	0.8177119	8336	0.9362801
1.146	0.1921035	3375	1.0924383	3060	0.8168795	8324	0.9361438
1.147	0.1924422	3387	1.0927458	3075	0.8160482	8313	0.9360073
1.148	0.1927820	3398	1.0930548	3090	0.8152182	8300	0.9358705
1.149	0.1931231	3411	1.0933654	3106	0.8143894	8288	0.9357335
1.150	0.1934653	3422	1.0936775	3121	0.8135619	8275	0.9355962

SAG CALCULATING TABLE FOR TRANSMISSION LINES

$\frac{s}{y} = \frac{sw}{p}$	Sag Factor	Diff.	Length Factor	Diff.	Stretch Factor	Diff.	Stretch X $\frac{s}{y}$
1.150	0.1934653	3435	1.0936775	3137	0.8135619	8263	0.9355962
1.151	0.1938088	3448	1.0939912	3152	0.8127356	8253	0.9354586
1.152	0.1941536	3460	1.0943064	3168	0.8119103	8240	0.9353207
1.153	0.1944996	3473	1.0946232	3184	0.8110863	8228	0.9351825
1.154	0.1948469	3486	1.0949416	3200	0.8102635	8216	0.9350441
1.155	0.1951955	3498	1.0952616	3217	0.8094419	8204	0.9349054
1.156	0.1955453	3511	1.0955833	3233	0.8086215	8192	0.9347665
1.157	0.1958964	3525	1.0959066	3250	0.8078023	8181	0.9346272
1.158	0.1962489	3538	1.0962316	3267	0.8069842	8169	0.9344877
1.159	0.1966027	3551	1.0965583	3283	0.8061673	8158	0.9343479
1.160	0.1969578	3565	1.0968866	3300	0.8053515	8146	0.9342078
1.161	0.1973143	3578	1.0972166	3318	0.8045369	8134	0.9340674
1.162	0.1976721	3593	1.0975484	3336	0.8037235	8123	0.9339267
1.163	0.1980314	3606	1.0978820	3353	0.8029112	8111	0.9337857
1.164	0.1983920	3620	1.0982173	3371	0.8021001	8100	0.9336445
1.165	0.1987540	3635	1.0985544	3389	0.8012901	8088	0.9335030
1.166	0.1991175	3649	1.0988933	3407	0.8004813	8077	0.9333612
1.167	0.1994824	3663	1.0992340	3426	0.7996736	8066	0.9332191
1.168	0.1998487	3678	1.0995766	3444	0.7988670	8054	0.9330767
1.169	0.2002165	3693	1.0999210	3463	0.7980616	8044	0.9329340
1.170	0.2005858	3707	1.1002673	3482	0.7972572	8031	0.9327910
1.171	0.2009565	3723	1.1006155	3501	0.7964541	8021	0.9326477
1.172	0.2013288	3738	1.1009656	3521	0.7956520	8010	0.9325041
1.173	0.2017026	3754	1.1013177	3540	0.7948510	7999	0.9323603
1.174	0.2020780	3770	1.1016717	3560	0.7940511	7988	0.9322160
1.175	0.2024550	3785	1.1020277	3580	0.7932523	7976	0.9320715
1.176	0.2028335	3801	1.1023857	3600	0.7924547	7965	0.9319267
1.177	0.2032136	3818	1.1027457	3621	0.7916582	7955	0.9317816
1.178	0.2035954	3833	1.1031078	3641	0.7908627	7944	0.9316363
1.179	0.2039787	3850	1.1034719	3662	0.7900683	7933	0.9314905
1.180	0.2043637	3867	1.1038381	3683	0.7892750	7922	0.9313445
1.181	0.2047504	3883	1.1042064	3705	0.7884828	7912	0.9311982
1.182	0.2051387	3901	1.1045769	3727	0.7876916	7901	0.9310515
1.183	0.2055288	3918	1.1049496	3748	0.7869015	7890	0.9309045
1.184	0.2059206	3935	1.1053244	3771	0.7861125	7879	0.9307572
1.185	0.2063141	3953	1.1057015	3793	0.7853246	7869	0.9306096
1.186	0.2067094	3970	1.1060808	3816	0.7845377	7858	0.9304617
1.187	0.2071064	3989	1.1064624	3838	0.7837519	7848	0.9303135
1.188	0.2075053	4007	1.1068462	3862	0.7829671	7837	0.9301649
1.189	0.2079060	4026	1.1072324	3885	0.7821834	7827	0.9300160
1.190	0.2083086	4045	1.1076209	3909	0.7814007	7817	0.9298668
1.191	0.2087131	4063	1.1080118	3933	0.7806190	7806	0.9297173
1.192	0.2091194	4082	1.1084051	3957	0.7798384	7796	0.9295674
1.193	0.2095276	4102	1.1088008	3982	0.7790588	7785	0.9294172
1.194	0.2099378	4121	1.1091990	4007	0.7782803	7775	0.9292667
1.195	0.2103499	4141	1.1095997	4033	0.7775028	7765	0.9291158
1.196	0.2107640	4161	1.1100030	4058	0.7767263	7755	0.9289646
1.197	0.2111801	4181	1.1104088	4084	0.7759508	7745	0.9288131
1.198	0.2115982	4202	1.1108172	4110	0.7751763	7735	0.9286612
1.199	0.2120184	4224	1.1112282	4136	0.7744028	7724	0.9285090
1.200	0.2124408		1.1116418		0.7736304		0.9283564

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
Solid Copper Wire (Soft Drawn)									
0000	2800	0.0005625	0.0000007897	0.0003750	0.0000005265	0.0002862	0.0000004018	0.0000003214	0.0000006207
000	2250	0.0006342	0.0000009022	0.0004228	0.0000006015	0.0002828	0.0000004023	0.0000003218	0.0000006791
00	1750	0.0007480	0.0000010439	0.0004987	0.0000006959	0.0003324	0.0000004639	0.0000003214	0.0000007496
0	1400	0.0008671	0.0000012203	0.0005781	0.0000008135	0.0003854	0.0000005423	0.0000003217	0.0000008374
1	1100	0.0010336	0.0000014422	0.0006891	0.0000009614	0.0004594	0.0000006410	0.0000003209	0.0000009437
2	900	0.0011944	0.0000017194	0.0007963	0.0000011463	0.0005308	0.0000007642	0.0000003231	0.0000010765
3	700	0.0014629	0.0000020662	0.0009752	0.0000013774	0.0006502	0.0000009183	0.0000003208	0.0000012369
4	550	0.0017836	0.0000024924	0.0011891	0.0000016616	0.0007927	0.0000011077	0.0000003201	0.0000014329
5	450	0.0021022	0.0000030321	0.0014015	0.0000020214	0.0009343	0.0000013476	0.0000003205	0.0000016795
6	350	0.0026200	0.0000037095	0.0017467	0.0000024730	0.0011644	0.0000016487	0.0000003196	0.0000019862
Solid Copper Wire (Hard Drawn)									
0000	4150	0.0003795	0.0000005923	0.0002530	0.0000003949	0.0001931	0.0000003013	0.0000002410	0.0000004655
000	3300	0.0004324	0.0000006767	0.0002883	0.0000004511	0.0001928	0.0000003017	0.0000002414	0.0000005093
00	2600	0.0005035	0.0000007829	0.0003356	0.0000005219	0.0002238	0.0000003480	0.0000002410	0.0000005622
0	2300	0.0005278	0.0000009152	0.0003519	0.0000006101	0.0002346	0.0000004067	0.0000002413	0.0000006280
1	1850	0.0006146	0.0000010816	0.0004097	0.0000007211	0.0002732	0.0000004807	0.0000002407	0.0000007078
2	1550	0.0006935	0.0000012896	0.0004623	0.0000008597	0.0003082	0.0000005732	0.0000002423	0.0000008074
3	1250	0.0008192	0.0000015496	0.0005461	0.0000010331	0.0003641	0.0000006887	0.0000002406	0.0000009277
4	1000	0.0009810	0.0000018693	0.0006540	0.0000012462	0.0004360	0.0000008308	0.0000002401	0.0000010747
5	800	0.0011825	0.0000022740	0.0007883	0.0000015160	0.0005256	0.0000010107	0.0000002404	0.0000012596
6	600	0.0015283	0.0000027821	0.0010189	0.0000018548	0.0006792	0.0000012365	0.0000002397	0.0000014897
Solid Copper Wire (Soft Drawn) Triple Braid Weather-Proofing									
0000	2800	0.0006561	0.0000009211	0.0004374	0.0000006141	0.0003425	0.0000004807	0.0000003846	0.0000007401
000	2250	0.0007493	0.0000010660	0.0004995	0.0000007107	0.0003494	0.0000004971	0.0000003977	0.0000008276
00	1750	0.0008674	0.0000012105	0.0005783	0.0000008070	0.0003855	0.0000005380	0.0000004003	0.0000009035
0	1400	0.0010243	0.0000014415	0.0006829	0.0000009610	0.0004552	0.0000006407	0.0000004091	0.0000010344
1	1100	0.0012073	0.0000016844	0.0008049	0.0000011230	0.0005366	0.0000007486	0.0000004008	0.0000011530
2	900	0.0014178	0.0000020409	0.0009452	0.0000013606	0.0006301	0.0000009071	0.0000004159	0.0000013484
3	700	0.0017257	0.0000024374	0.0011505	0.0000016250	0.0007670	0.0000010833	0.0000004015	0.0000015395
4	550	0.0020782	0.0000029040	0.0013855	0.0000019360	0.0009236	0.0000012906	0.0000004167	0.0000017734
5	450	0.0024733	0.0000035673	0.0016489	0.0000023782	0.0010992	0.0000015854	0.0000004327	0.0000021154
6	350	0.0030974	0.0000043851	0.0020649	0.0000029234	0.0013766	0.0000019489	0.0000004531	0.0000025364

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Solid Copper Wire (Hard Drawn) Triple Braid Weather-Proofing

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
0000	4150	0.0004427	0.0000006908	0.0002951	0.0000004606	0.0002310	0.0000003605	0.0000002884	0.0000005551
000	3300	0.0005109	0.0000007995	0.0003406	0.0000005330	0.0002383	0.0000003728	0.0000002983	0.0000006207
00	2600	0.0005838	0.0000009079	0.0003892	0.0000006053	0.0002595	0.0000004035	0.0000003002	0.0000006776
0	2300	0.0006235	0.0000010811	0.0004157	0.0000007207	0.0002771	0.0000004805	0.0000003068	0.0000007758
1	1850	0.0007178	0.0000012633	0.0004785	0.0000008422	0.0003190	0.0000005615	0.0000003006	0.0000008648
2	1550	0.0008232	0.0000015307	0.0005488	0.0000010205	0.0003659	0.0000006803	0.0000003119	0.0000010113
3	1250	0.0009664	0.0000018281	0.0006443	0.0000012187	0.0004295	0.0000008125	0.0000003012	0.0000011546
4	1000	0.0011430	0.0000021780	0.0007620	0.0000014520	0.0005080	0.0000009680	0.0000003125	0.0000013301
5	800	0.0013912	0.0000026755	0.0009275	0.0000017837	0.0006183	0.0000011891	0.0000003245	0.0000015866
6	600	0.0018067	0.0000032888	0.0012044	0.0000021926	0.0008030	0.0000014617	0.0000003398	0.0000019023

Stranded Copper Wire (Soft Drawn)

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
500 M	6650	0.0003970	0.0000007576	0.0002866	0.0000005471	0.0002866	0.0000005471	0.0000004377	0.0000006730
450 M	6000	0.0004107	0.0000007776	0.0002860	0.0000005416	0.0002860	0.0000005416	0.0000004333	0.0000006826
400 M	5350	0.0004288	0.0000008061	0.0002851	0.0000005359	0.0002851	0.0000005359	0.0000004287	0.0000006972
350 M	4650	0.0004559	0.0000008409	0.0003039	0.0000005606	0.0002871	0.0000005295	0.0000004236	0.0000007143
300 M	4000	0.0004872	0.0000008880	0.0003248	0.0000005920	0.0002859	0.0000005211	0.0000004169	0.0000007372
250 M	3350	0.0005337	0.0000009584	0.0003558	0.0000006389	0.0002843	0.0000005105	0.0000004084	0.0000007718
0000	2800	0.0005861	0.0000010096	0.0003907	0.0000006731	0.0002879	0.0000004960	0.0000003968	0.0000007912
000	2250	0.0006600	0.0000010956	0.0004400	0.0000007304	0.0002967	0.0000004869	0.0000003785	0.0000008234
00	1750	0.0007777	0.0000011670	0.0005185	0.0000007780	0.0003456	0.0000005187	0.0000003481	0.0000008386
0	1400	0.0009007	0.0000013485	0.0006005	0.0000008990	0.0004003	0.0000005993	0.0000003443	0.0000009261
1	1100	0.0010682	0.0000015444	0.0007121	0.0000010296	0.0004747	0.0000006864	0.0000003352	0.0000010134
2	900	0.0012300	0.0000018068	0.0008200	0.0000012045	0.0005467	0.0000008030	0.0000003313	0.0000011343
3	700	0.0015043	0.0000021525	0.0010029	0.0000014350	0.0006686	0.0000009567	0.0000003271	0.0000012939
4	550	0.0018291	0.0000025765	0.0012194	0.0000017177	0.0008129	0.0000011451	0.0000003253	0.0000014906
5	450	0.0021556	0.0000031265	0.0014370	0.0000020843	0.0009580	0.0000013895	0.0000003255	0.0000017405
6	350	0.0026743	0.0000038018	0.0017829	0.0000025345	0.0011886	0.0000016897	0.0000003249	0.0000020512

Modulus of elasticity (e) of stranded wire is considered as being reduced from that for solid wire, in the same ratio as was shown by tests on Copper Clad Steel Wire.

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Stranded Copper Wire (Hard Drawn)

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
500 M	11750	0.0002247	0.0000005682	0.0001622	0.0000004103	0.0001622	0.0000004103	0.0000003282	0.0000005047
450 M	10600	0.0002325	0.0000005832	0.0001619	0.0000004062	0.0001619	0.0000004062	0.0000003250	0.0000005119
400 M	9400	0.0002440	0.0000006046	0.0001622	0.0000004019	0.0001622	0.0000004019	0.0000003215	0.0000005229
350 M	8250	0.0002570	0.0000006307	0.0001713	0.0000004204	0.0001618	0.0000003971	0.0000003177	0.0000005358
300 M	7100	0.0002745	0.0000006660	0.0001830	0.0000004440	0.0001611	0.0000003908	0.0000003127	0.0000005529
250 M	5900	0.0003031	0.0000007188	0.0002020	0.0000004792	0.0001614	0.0000003829	0.0000003063	0.0000005789
0000	5000	0.0003282	0.0000007572	0.0002188	0.0000005048	0.0001612	0.0000003720	0.0000002976	0.0000005934
000	3950	0.0003759	0.0000008217	0.0002506	0.0000005478	0.0001671	0.0000003652	0.0000002839	0.0000006175
00	3150	0.0004321	0.0000008753	0.0002880	0.0000005835	0.0001920	0.0000003890	0.0000002611	0.0000006290
0	2500	0.0005044	0.0000010114	0.0003363	0.0000006743	0.0002242	0.0000004495	0.0000002582	0.0000006946
1	1950	0.0006026	0.0000011583	0.0004017	0.0000007722	0.0002678	0.0000005148	0.0000002514	0.0000007600
2	1550	0.0007142	0.0000013551	0.0004761	0.0000009034	0.0003174	0.0000006023	0.0000002485	0.0000008507
3	1250	0.0008424	0.0000016144	0.0005616	0.0000010763	0.0003744	0.0000007175	0.0000002453	0.0000009704
4	1000	0.0010060	0.0000019324	0.0006706	0.0000012883	0.0004471	0.0000008589	0.0000002440	0.0000011179
5	800	0.0012125	0.0000023449	0.0008083	0.0000015633	0.0005389	0.0000010422	0.0000002441	0.0000013054
6	600	0.0015600	0.0000028514	0.0010400	0.0000019009	0.0006933	0.0000012673	0.0000002437	0.0000015384

Stranded Copper Wire (Soft Drawn), Weather-Proofed

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
500 M	6650	0.0004838	0.0000009232	0.0003560	0.0000006794	0.0003560	0.0000006794	0.0000005436	0.0000008305
450 M	6000	0.0005053	0.0000009568	0.0003592	0.0000006801	0.0003592	0.0000006801	0.0000005441	0.0000008524
400 M	5350	0.0005305	0.0000009973	0.0003628	0.0000006822	0.0003628	0.0000006822	0.0000005457	0.0000008778
350 M	4650	0.0005632	0.0000010388	0.0003755	0.0000006925	0.0003615	0.0000006668	0.0000005345	0.0000008980
300 M	4000	0.0006080	0.0000011061	0.0004053	0.0000007374	0.0003669	0.0000006686	0.0000005349	0.0000009404
250 M	3350	0.0006618	0.0000011883	0.0004412	0.0000007922	0.0003675	0.0000006600	0.0000005280	0.0000009820
0000	2800	0.0007118	0.0000012262	0.0004745	0.0000008174	0.0003571	0.0000006152	0.0000004922	0.0000009838
000	2250	0.0008116	0.0000013472	0.0005411	0.0000008981	0.0003628	0.0000006022	0.0000004818	0.0000010454
00	1750	0.0009520	0.0000014286	0.0006347	0.0000009524	0.0004231	0.0000006349	0.0000004476	0.0000010676
0	1400	0.0011014	0.0000016490	0.0007343	0.0000010993	0.0004895	0.0000007329	0.0000004534	0.0000011881
1	1100	0.0012682	0.0000018336	0.0008455	0.0000012224	0.0005637	0.0000008149	0.0000004311	0.0000012631
2	900	0.0014278	0.0000020973	0.0009519	0.0000013982	0.0006346	0.0000009321	0.0000004407	0.0000013955
3	700	0.0017343	0.0000024816	0.0011562	0.0000016544	0.0007708	0.0000011029	0.0000004211	0.0000015760
4	550	0.0021182	0.0000029837	0.0014121	0.0000019891	0.0009414	0.0000013261	0.0000004354	0.0000018363
5	450	0.0024933	0.0000036164	0.0016622	0.0000024109	0.0011081	0.0000016073	0.0000004512	0.0000021563
6	350	0.0031029	0.0000044110	0.0020686	0.0000029407	0.0013791	0.0000019605	0.0000004671	0.0000025548

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Stranded Copper Wire (Hard Drawn), Weather-Proofed

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
500 M	11750	0.0002738	0.0000006924	0.0002015	0.0000005096	0.0002015	0.0000005096	0.0000004077	0.000006229
450 M	10600	0.0002860	0.0000007176	0.0002033	0.0000005101	0.0002033	0.0000005101	0.0000004081	0.000006393
400 M	9400	0.0003019	0.0000007480	0.0002065	0.0000005116	0.0002065	0.0000005116	0.0000004093	0.000006584
350 M	8250	0.0003175	0.0000007791	0.0002116	0.0000005194	0.0002038	0.0000005001	0.0000004009	0.000006735
300 M	7100	0.0003425	0.0000008296	0.0002283	0.0000005531	0.0002067	0.0000005014	0.0000004012	0.000007053
250 M	5900	0.0003758	0.0000008912	0.0002505	0.0000005942	0.0002087	0.0000004950	0.0000003960	0.000007365
0000	5000	0.0003986	0.0000009196	0.0002657	0.0000006131	0.0002000	0.0000004614	0.0000003692	0.000007378
000	3950	0.0004623	0.0000010104	0.0003082	0.0000006736	0.0002066	0.0000004516	0.0000003614	0.000007841
00	3150	0.0005289	0.0000010714	0.0003526	0.0000007143	0.0002351	0.0000004762	0.0000003357	0.000008007
0	2500	0.0006168	0.0000012368	0.0004112	0.0000008245	0.0002741	0.0000005497	0.0000003401	0.000008911
1	1950	0.0007154	0.0000013752	0.0004769	0.0000009168	0.0003179	0.0000006112	0.0000003233	0.000009473
2	1550	0.0008290	0.0000015730	0.0005526	0.0000010486	0.0003684	0.0000006991	0.0000003305	0.0000010466
3	1250	0.0009712	0.0000018612	0.0006475	0.0000012408	0.0004317	0.0000008272	0.0000003158	0.0000011820
4	1000	0.0011650	0.0000022378	0.0007766	0.0000014919	0.0005177	0.0000009946	0.0000003265	0.0000013772
5	800	0.0014025	0.0000027123	0.0009350	0.0000018082	0.0006233	0.0000012055	0.0000003384	0.0000016172
6	600	0.0018100	0.0000033082	0.0012067	0.0000022055	0.0008045	0.0000014704	0.0000003503	0.0000019161

Copper Clad Steel ("Copperweld"), Solid, Bare (Copper Clad Steel Company)

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
0000	4925	0.0003111	0.0000004608	0.0002074	0.0000003072	0.0001486	0.0000002202	0.0000001760	0.0000003559
000	4140	0.0003377	0.0000005303	0.0002251	0.0000003535	0.0001502	0.0000002357	0.0000001772	0.0000003923
00	3425	0.0003752	0.0000006148	0.0002501	0.0000004099	0.0001675	0.0000002733	0.0000001770	0.0000004349
0	2850	0.0004193	0.0000007208	0.0002795	0.0000004805	0.0001863	0.0000003203	0.0000001767	0.0000004867
1	2400	0.0004688	0.0000008555	0.0003125	0.0000005703	0.0002084	0.0000003802	0.0000001757	0.0000005498
2	2000	0.0005325	0.0000010211	0.0003550	0.0000006807	0.0002367	0.0000004538	0.0000001764	0.0000006290
3	1600	0.0006356	0.0000012300	0.0004237	0.0000008200	0.0002825	0.0000005467	0.0000001766	0.0000007257
4	1325	0.0007351	0.0000014857	0.0004901	0.0000009909	0.0003267	0.0000006606	0.0000001769	0.0000008450
5	1100	0.0008564	0.0000018115	0.0005709	0.0000012077	0.0003806	0.0000008051	0.0000001769	0.0000009942
6	900	0.0010156	0.0000022163	0.0006770	0.0000014775	0.0004514	0.0000009850	0.0000001770	0.0000011760
7	730	0.0012192	0.0000027217	0.0008128	0.0000018145	0.0005419	0.0000012097	0.0000001774	0.0000014037
8	600	0.0014500	0.0000033539	0.0009667	0.0000022359	0.0006444	0.0000014906	0.0000001773	0.0000016847
9	490	0.0017408	0.0000041488	0.0011605	0.0000027659	0.0007737	0.0000018439	0.0000001800	0.0000020379
10	400	0.0020950	0.0000051380	0.0013967	0.0000034253	0.0009311	0.0000022835	0.0000001778	0.0000024709
11	325	0.0025385	0.0000063756	0.0016923	0.0000042504	0.0011282	0.0000028336	0.0000001777	0.0000030216
12	260	0.0031346	0.0000079435	0.0020897	0.0000052957	0.0013932	0.0000035304	0.0000001755	0.0000036940
14	165	0.0048242	0.0000123602	0.0032162	0.0000082402	0.0021441	0.0000054934	0.0000001801	0.0000056211

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Copper Clad Steel ("Copperweld"), Solid Weather-Proofed

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
2	2000	0.0006265	0.0000012013	0.0004177	0.0000008009	0.0002784	0.0000005339	0.0000002147	0.0000007686
4	1330	0.0008466	0.0000017175	0.0005644	0.0000011450	0.0003763	0.0000007633	0.0000002151	0.0000010250
6	900	0.0011578	0.0000025267	0.0007719	0.0000016844	0.0005146	0.0000011230	0.0000002279	0.0000014234
8	600	0.0016450	0.0000038049	0.0010967	0.0000025366	0.0007311	0.0000016911	0.0000002390	0.0000020393
9	490	0.0019735	0.0000047033	0.0013157	0.0000031355	0.0008771	0.0000020903	0.0000002480	0.0000024708
10	400	0.0023700	0.0000058124	0.0015800	0.0000038749	0.0010533	0.0000025833	0.0000002636	0.0000030043
12	260	0.0035154	0.0000089084	0.0023436	0.0000059389	0.0015624	0.0000039593	0.0000002729	0.0000044444

Copper Clad Steel ("Copperweld"), Stranded Bare

37 Wire Strands

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
1 1/4"	40700	0.0001193	0.0000003563	0.0001076	0.0000003215	0.0001076	0.0000003215	0.0000002572	0.0000003382
1 1/8"	33300	0.0001217	0.0000003742	0.0001044	0.0000003207	0.0001044	0.0000003207	0.0000002566	0.0000003503
1"	26825	0.0001275	0.0000003927	0.0001030	0.0000003170	0.0001030	0.0000003170	0.0000002537	0.0000003611
7/8"	22200	0.0001311	0.0000004154	0.0000988	0.0000003129	0.0000988	0.0000003129	0.0000002503	0.0000003741

19 Wire Strands

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
7/8"	20900	0.0001418	0.0000004101	0.0001077	0.0000003113	0.0001077	0.0000003113	0.0000002491	0.0000003704
13/16"	17100	0.0001492	0.0000004384	0.0001046	0.0000003071	0.0001046	0.0000003071	0.0000002457	0.0000003860
3/4"	15600	0.0001531	0.0000004513	0.0001029	0.0000003035	0.0001029	0.0000003035	0.0000002428	0.0000003923
23/32"	13800	0.0001604	0.0000004699	0.0001070	0.0000003132	0.0001028	0.0000003011	0.0000002409	0.0000004020
11/16"	12550	0.0001645	0.0000004907	0.0001097	0.0000003272	0.0000996	0.0000002971	0.0000002376	0.0000004121
5/8"	11400	0.0001706	0.0000005117	0.0001137	0.0000003411	0.0000987	0.0000002960	0.0000002368	0.0000004233
9/16"	9220	0.0001882	0.0000005631	0.0001254	0.0000003754	0.0000982	0.0000002937	0.0000002350	0.0000004489

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Copper Clad Steel ("Copperweld"), Stranded Bare

7 Wire Strands

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
5/8"	9280	0.0002013	0.0000005228	0.0001342	0.0000003485	0.0001126	0.0000002925	0.0000002340	0.000004276
9/16"	7700	0.0002158	0.0000005707	0.0001439	0.0000003805	0.0001077	0.0000002846	0.0000002277	0.000004478
0000	7150	0.0002236	0.0000005838	0.0001491	0.0000003892	0.0001060	0.0000002766	0.0000002212	0.000004513
1/2"	6300	0.0002397	0.0000006204	0.0001598	0.0000004136	0.0001065	0.0000002757	0.0000002161	0.000004680
000	5820	0.0002505	0.0000006423	0.0001670	0.0000004282	0.0001113	0.0000002855	0.0000002119	0.000004753
7/16"	5080	0.0002719	0.0000006806	0.0001812	0.0000004538	0.0001208	0.0000003025	0.0000002060	0.000004919
00	4730	0.0002831	0.0000007047	0.0001887	0.0000004698	0.0001258	0.0000003132	0.0000002011	0.000004989
3/8"	4200	0.0003040	0.0000007543	0.0002027	0.0000005028	0.0001351	0.0000003352	0.0000001961	0.000005210
0	3890	0.0003190	0.0000007840	0.0002127	0.0000005226	0.0001418	0.0000003484	0.0000001908	0.000005319
11/32"	3400	0.0003512	0.0000008652	0.0002341	0.0000005768	0.0001561	0.0000003845	0.0000001935	0.000005732
5/16"	2800	0.0004014	0.0000010099	0.0002676	0.0000006733	0.0001784	0.0000004488	0.0000001878	0.000006379
9/32"	2280	0.0004680	0.0000011975	0.0003120	0.0000007984	0.0002080	0.0000005322	0.0000001863	0.000007262
1/4"	1820	0.0005593	0.0000014278	0.0003729	0.0000009518	0.0002486	0.0000006346	0.0000001809	0.000008289
3/16"	1160	0.0008155	0.0000021022	0.0005437	0.0000014015	0.0003624	0.0000009343	0.0000001844	0.000011400

Steel Reinforced Aluminum Wire, Stranded, Bare (Aluminum Co. of America)

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
605 M	14785	0.0001434	0.0000003461	0.0000956	0.0000002307	0.0000637	0.0000001592	0.0000001273	0.000002727
500 M	17035	0.0001215	0.0000003316	0.0000810	0.0000002211	0.0000570	0.0000001561	0.0000001249	0.000002635
336.4 M	11710	0.0001477	0.0000004094	0.0000985	0.0000002729	0.0000657	0.0000001819	0.0000001249	0.000003052
266.8 M	6470	0.0002334	0.0000005584	0.0001556	0.0000003723	0.0001037	0.0000002482	0.0000001272	0.000004031
0000	5940	0.0002374	0.0000006060	0.0001582	0.0000004040	0.0001055	0.0000002693	0.0000001268	0.000004066
000	4690	0.0002793	0.0000007100	0.0001862	0.0000004733	0.0001241	0.0000003155	0.0000001257	0.000004585
00	3730	0.0003298	0.0000008407	0.0002198	0.0000005605	0.0001466	0.0000003737	0.0000001265	0.000005202
0	2960	0.0003919	0.0000009995	0.0002613	0.0000006663	0.0001742	0.0000004442	0.0000001267	0.000005980
1	2350	0.0004723	0.0000012068	0.0003149	0.0000008045	0.0002099	0.0000005363	0.0000001272	0.000006936
2	1860	0.0005699	0.0000014532	0.0003799	0.0000009688	0.0002533	0.0000006459	0.0000001267	0.000008089
3	1480	0.0006892	0.0000017641	0.0004595	0.0000011761	0.0003063	0.0000007840	0.0000001269	0.000009011
4	1170	0.0008385	0.0000021363	0.0005590	0.0000014242	0.0003727	0.0000009495	0.0000001263	0.000011237
5	930	0.0010215	0.0000026099	0.0006810	0.0000017399	0.0004540	0.0000011600	0.0000001274	0.000013489
6	730	0.0012658	0.0000032039	0.0008438	0.0000021359	0.0005626	0.0000014239	0.0000001262	0.000016089
7	580	0.0015517	0.0000039439	0.0010345	0.0000026293	0.0006897	0.0000017528	0.0000001249	0.000019369
8	460	0.0019152	0.0000048407	0.0012768	0.0000032271	0.0008512	0.0000021514	0.0000001264	0.000023407

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
Steel Reinforced Aluminum Wire, Stranded, Double Braid Weather-Proofed									
605 M	14785	0.0001769	0.0000004269	0.0001179	0.0000002846	0.0000877	0.0000002116	0.0000001693	0.0000003485
500 M	17035	0.0001382	0.0000004056	0.0000988	0.0000002704	0.0000741	0.0000002029	0.0000001623	0.0000003294
336.4 M	11710	0.0001755	0.0000004863	0.0001170	0.0000003242	0.0000780	0.0000002161	0.0000001621	0.0000003760
266.8 M	6470	0.0002774	0.0000006638	0.0001850	0.0000004425	0.0001233	0.0000002950	0.0000001675	0.0000004800
0000	5940	0.0002746	0.0000007010	0.0001831	0.0000004673	0.0001220	0.0000003115	0.0000001646	0.0000004942
000	4690	0.0003249	0.0000008259	0.0002166	0.0000005506	0.0001444	0.0000003671	0.0000001680	0.0000005631
00	3730	0.0003737	0.0000009528	0.0002492	0.0000006352	0.0001661	0.0000004235	0.0000001668	0.0000006247
0	2960	0.0004203	0.0000010719	0.0002802	0.0000007146	0.0001868	0.0000004764	0.0000001611	0.0000006720
1	2350	0.0005072	0.0000012959	0.0003381	0.0000008640	0.0002254	0.0000005760	0.0000001631	0.0000007860
2	1860	0.0006172	0.0000015739	0.0004115	0.0000010493	0.0002743	0.0000006995	0.0000001686	0.0000009282
3	1480	0.0007480	0.0000019146	0.0004986	0.0000012764	0.0003324	0.0000008509	0.0000001764	0.0000011000
4	1170	0.0009137	0.0000023280	0.0006091	0.0000015520	0.0004061	0.0000010346	0.0000001829	0.0000013044
5	930	0.0011118	0.0000028407	0.0007412	0.0000018938	0.0004941	0.0000012625	0.0000001950	0.0000015549
6	730	0.0013699	0.0000034674	0.0009132	0.0000023116	0.0006088	0.0000015411	0.0000002080	0.0000018585
7	580	0.0016879	0.0000042901	0.0011253	0.0000028601	0.0007502	0.0000019067	0.0000002147	0.0000022568
8	460	0.0020913	0.0000052857	0.0013942	0.0000035238	0.0009295	0.0000023492	0.0000002253	0.0000027363
Steel Reinforced Aluminum Wire, Stranded, Triple Braid Weather-Proofed									
605 M	14785	0.0001834	0.0000004427	0.0001222	0.0000002951	0.0000917	0.0000002214	0.0000001771	0.0000003628
500 M	17035	0.0001525	0.0000004174	0.0001017	0.0000002782	0.0000770	0.0000002109	0.0000001687	0.0000003419
336.4 M	11710	0.0001827	0.0000005064	0.0001218	0.0000003376	0.0000812	0.0000002251	0.0000001711	0.0000003940
266.8 M	6470	0.0002921	0.0000006989	0.0001947	0.0000004659	0.0001298	0.0000003106	0.0000001867	0.0000005136
0000	5940	0.0002865	0.0000007315	0.0001910	0.0000004877	0.0001273	0.0000003251	0.0000001732	0.0000005196
000	4690	0.0003397	0.0000008633	0.0002264	0.0000005756	0.0001509	0.0000003837	0.0000001778	0.0000005940
00	3730	0.0003887	0.0000009959	0.0002592	0.0000006639	0.0001728	0.0000004426	0.0000001736	0.0000006582
0	2960	0.0004412	0.0000011253	0.0002941	0.0000007502	0.0001961	0.0000005001	0.0000001689	0.0000007134
1	2350	0.0005336	0.0000013633	0.0003557	0.0000009089	0.0002372	0.0000006059	0.0000001718	0.0000008371
2	1860	0.0006495	0.0000016562	0.0004330	0.0000011041	0.0002887	0.0000007361	0.0000001782	0.0000009899
3	1480	0.0007892	0.0000020201	0.0005261	0.0000013467	0.0003507	0.0000008978	0.0000001885	0.0000011795
4	1170	0.0009641	0.0000024564	0.0006427	0.0000016376	0.0004285	0.0000010917	0.0000001938	0.0000014003
5	930	0.0011753	0.0000030027	0.0007835	0.0000020018	0.0005223	0.0000013345	0.0000002115	0.0000016786
6	730	0.0014493	0.0000036685	0.0009662	0.0000024457	0.0006441	0.0000016305	0.0000002254	0.0000020111
7	580	0.0017887	0.0000045486	0.0011924	0.0000030324	0.0007950	0.0000020216	0.0000002322	0.0000024452
8	460	0.0022152	0.0000055989	0.0014768	0.0000037326	0.0009845	0.0000024884	0.0000002417	0.0000029615

Above Tables are based on the assumption that stress is taken by both steel and aluminum, assumed stress being the elastic limit, as given in The Aluminum Company of America Hand Book. Elasticity of wires has been based on formulas given in same book.

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Steel Reinforced Aluminum Wire, Stranded, Bare. Steel assumed to carry all the load.

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
605 M	7210	0.0002941	0.0000011476	0.0001961	0.0000007651	0.0001306	0.0000005279	0.0000004220	0.0000009042
500 M	10490	0.0001973	0.0000007675	0.0001315	0.0000005117	0.0000926	0.0000003613	0.0000002890	0.0000006098
336.4 M	7210	0.0002399	0.0000009355	0.0001599	0.0000006237	0.0001066	0.0000004158	0.0000002854	0.0000006974
266.8 M	3200	0.0007419	0.0000018420	0.0004946	0.0000012280	0.0003297	0.0000008187	0.0000004196	0.0000013297
0000	3600	0.0003917	0.0000016968	0.0002611	0.0000011312	0.0001741	0.0000007541	0.0000003550	0.0000011385
000	2850	0.0004596	0.0000019880	0.0003064	0.0000013253	0.0002043	0.0000008835	0.0000003520	0.0000012838
00	2260	0.0005442	0.0000023540	0.0003628	0.0000015693	0.0002419	0.0000010462	0.0000003542	0.0000014566
0	1800	0.0006444	0.0000027986	0.0004296	0.0000018657	0.0002864	0.0000012438	0.0000003548	0.0000016744
1	1420	0.0007816	0.0000033790	0.0005211	0.0000022526	0.0003474	0.0000015017	0.0000003562	0.0000019421
2	1130	0.0009381	0.0000040690	0.0006254	0.0000027127	0.0004169	0.0000018085	0.0000003548	0.0000022649
3	880	0.0011591	0.0000049395	0.0007727	0.0000032930	0.0005151	0.0000021953	0.0000003553	0.0000025231
4	710	0.0013818	0.0000059816	0.0009212	0.0000039877	0.0006141	0.0000026585	0.0000003536	0.0000031464
5	560	0.0016964	0.0000073077	0.0011309	0.0000048718	0.0007539	0.0000032479	0.0000003567	0.0000037769
6	450	0.0020535	0.0000089709	0.0013690	0.0000059806	0.0009126	0.0000039871	0.0000003534	0.0000045049
7	360	0.0025000	0.0000110429	0.0016667	0.0000073619	0.0011111	0.0000049079	0.0000003497	0.0000054233
8	280	0.0031464	0.0000135540	0.0020976	0.0000090360	0.0013984	0.0000060240	0.0000003539	0.0000065540

Steel Reinforced Aluminum Wire, Stranded, D. B. W. P. Steel assumed to carry all the load.

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{ae}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{ae}$
605 M	7210	0.0003628	0.0000014155	0.0002418	0.0000009437	0.0001798	0.0000007016	0.0000005614	0.0000011556
500 M	10490	0.0002407	0.0000009387	0.0001605	0.0000006258	0.0001203	0.0000004696	0.0000003756	0.0000007624
336.4 M	7210	0.0002850	0.0000011112	0.0001900	0.0000007408	0.0001267	0.0000004938	0.0000003704	0.0000008592
266.8 M	3200	0.0005609	0.0000021897	0.0003741	0.0000014597	0.0002493	0.0000009731	0.0000005525	0.0000015834
0000	3600	0.0004531	0.0000019628	0.0003021	0.0000013084	0.0002013	0.0000008722	0.0000004609	0.0000013838
000	2850	0.0005364	0.0000023125	0.0003576	0.0000015417	0.0002384	0.0000010279	0.0000004704	0.0000015767
00	2260	0.0006168	0.0000026678	0.0004113	0.0000017786	0.0002742	0.0000011858	0.0000004670	0.0000017492
0	1800	0.0006911	0.0000030013	0.0004607	0.0000020009	0.0003072	0.0000013339	0.0000004511	0.0000018816
1	1420	0.0008394	0.0000036285	0.0005595	0.0000024192	0.0003730	0.0000016128	0.0000004567	0.0000022008
2	1130	0.0010159	0.0000044069	0.0006773	0.0000029380	0.0004515	0.0000019586	0.0000004721	0.0000025990
3	880	0.0012580	0.0000053609	0.0008386	0.0000035739	0.0005590	0.0000023825	0.0000004939	0.0000030800
4	710	0.0015057	0.0000065184	0.0010038	0.0000043456	0.0006692	0.0000028969	0.0000005121	0.0000036523
5	560	0.0018464	0.0000079540	0.0012309	0.0000053026	0.0008206	0.0000035350	0.0000005460	0.0000043537
6	450	0.0022223	0.0000097087	0.0014814	0.0000064725	0.0009876	0.0000043151	0.0000005824	0.0000052038
7	360	0.0027194	0.0000120123	0.0018130	0.0000080083	0.0012086	0.0000053388	0.0000006012	0.0000063190
8	280	0.0034358	0.0000148000	0.0022905	0.0000098666	0.0015270	0.0000065778	0.0000006308	0.0000076616

TABLE OF WIRE CONSTANTS FOR SAG CALCULATIONS

Steel Reinforced Aluminum Wire, Stranded, T. B. W. P. Steel assumed to carry all the load.

Size of Wire	Assumed Tension "p"	Heavy Loading $\frac{w}{p}$	Heavy Loading $\frac{w}{as}$	Medium Loading $\frac{w}{p}$	Medium Loading $\frac{w}{ae}$	Light Loading $\frac{w}{p}$	Light Loading $\frac{w}{ae}$	Unloaded Wire $\frac{w'}{ae}$	Wire+1/2" Ice $\frac{w''}{as}$
605 M	7210	0.0003761	0.0000014679	0.0002506	0.0000009785	0.0001880	0.0000007341	0.0000005872	0.0000012030
500 M	10490	0.0002477	0.0000009660	0.0001652	0.0000006440	0.0001250	0.0000004881	0.0000003904	0.0000007913
336.4 M	7210	0.0002967	0.0000011571	0.0001978	0.0000007714	0.0001319	0.0000005143	0.0000003910	0.0000009003
266.8 M	3200	0.0005906	0.0000023055	0.0003937	0.0000015370	0.0002624	0.0000010246	0.0000006159	0.0000016942
0000	3600	0.0004728	0.0000020482	0.0003152	0.0000013655	0.0002101	0.0000009103	0.0000004850	0.0000014549
000	2850	0.0005608	0.0000024172	0.0003738	0.0000016117	0.0002491	0.0000010744	0.0000004978	0.0000016632
00	2260	0.0006415	0.0000027885	0.0004278	0.0000018589	0.0002852	0.0000012393	0.0000004861	0.0000018430
0	1800	0.0007255	0.0000031508	0.0004837	0.0000021006	0.0003225	0.0000014003	0.0000004729	0.0000019975
1	1420	0.0008831	0.0000038172	0.0005887	0.0000025449	0.0003925	0.0000016965	0.0000004810	0.0000023439
2	1130	0.0010691	0.0000046374	0.0007127	0.0000030915	0.0004752	0.0000020611	0.0000004990	0.0000027717
3	880	0.0013273	0.0000056563	0.0008848	0.0000037708	0.0005898	0.0000025138	0.0000005278	0.0000033026
4	710	0.0015887	0.0000068779	0.0010591	0.0000045853	0.0007061	0.0000030568	0.0000005426	0.0000039208
5	560	0.0019518	0.0000084076	0.0013012	0.0000056050	0.0008674	0.0000037366	0.0000005922	0.0000047001
6	450	0.0023511	0.0000102718	0.0015674	0.0000068480	0.0010449	0.0000045654	0.0000006311	0.0000056311
7	360	0.0028818	0.0000127361	0.0019212	0.0000084907	0.0012808	0.0000056605	0.0000006502	0.0000068466
8	280	0.0036394	0.0000156769	0.0024262	0.0000104513	0.0016175	0.0000069675	0.0000006768	0.0000082922

Note, that in all the foregoing tables of wire constants, if any other tension in the wire than that named in the table is assumed, then the value of w/p must be changed in the inverse ratio. For example; if a tension under maximum conditions is assumed, which is one half as great as that given in the table, then the value of w/p must be doubled.

The assumed tension given in all cases of copper and copper clad steel wire, is one half the ultimate strength. In the first set of tables on steel reinforced aluminum wire, the assumed tension is the elastic limit, as given in the hand book of the manufacturing company. In the case of the second set, in which the steel is assumed to take all the load, the assumed stress, is on a basis of 130,000 pounds per square inch on the steel, where a single steel wire is used, and 117,000 pounds, where the steel core is stranded

DISCUSSION

Mr. O. M. Jorstad:* Mr. Martin spoke of the vagueness of the modulus of elasticity of a stranded cable and at the same time I think he used on his chart 16,000,000 for stranded copper. That seems to be the figure universally used. I was just wondering whether there is any doubt about that figure.

Mr. James S. Martin: It is safer to figure the sags by that method and use a figure a little too high than a little too low; because, if you assume a modulus of elasticity less than the actual value your calculations will give you a smaller value for the sag than that actually required. Everything considered, it is better to assume your modulus of elasticity a little too high than too low. For that reason it is slightly on the safe side to assume 16,000,000 though if put to a test I think stranded wire will show a lower modulus of elasticity.

Mr. L. F. W. Hildner, *Chairman*:† In the large towers of river spans, are connections riveted or bolted?

Mr. James S. Martin: The field connections are bolted.

Mr. L. F. W. Hildner, *Chairman*: Is there no riveting at all done in the field?

Mr. James S Martin: Not in the erection.

Mr. N. A. Wahlberg:‡ What size bolts or rivets are used on tower construction and what size is the plate on the tower arm where the insulators are connected?

Mr. James S. Martin: Ordinarily ⅝-inch bolts are used, and as the work grows heavier we use ¾-inch and in a very few

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†Vice-President and Chief Engineer, Pittsburgh Bridge & Iron Works, Pittsburgh.

‡Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

cases, ⅞-inch. To connect the insulators to the cross-arms we use 6- by 3½- by ½-inch angles.

Mr. N. A. Wahlberg: Is any wearing of the plate noticeable, due to the oscillation of the tower and the span?

Mr. James S. Martin: We have never had any noticeable wear. There is very little motion to the connecting hooks, especially on the long spans where there is practically no swaying of the wire itself, and I do not think there has ever been any noticeable wear reported.

Mr. N. A. Wahlberg: I am interested in the matter of standardization. In suspension insulators should half-inch or three-quarter inch pins be used?

Mr. James S. Martin: Our practice is to connect insulators to a connection plate or angle with a hook. Our standard hook requires a hole 1 1/16 inches in diameter.

Mr. George S. Humphrey:* I should like to know whether you use tinned copper protecting sleeves between the clamp and the copper conductor to protect the conductor against mechanical injury or electrolytic action between the copper and zinc; also, why you figure 6750 pounds stress on a dead end when the maximum stress on the wire is figured at 4500; also whether or not you ever used a dynamometer for sagging wire?

Mr. James S. Martin: Our company does not use sleeves between the clamp and the wire; the bare wire is passed through the clamp and the bolts tightened. The 6750 pounds is the resultant of two pulls of 4500 pounds acting at right angles to each other. This is used for the 90-degree towers. We have never used the dynamometer in stringing wires. That brings to my mind something I had thought of mentioning. Some spans have been put up by means of weights running over pulleys, which insures a uniform tension at all times. That is all right as long as there are no wires one above the other—as long as they are all in one hori-

*Electrical Engineer, West Penn Power Co., Pittsburgh.

zontal plane—but as soon as your tower is narrowed down so that wires must be placed one above another, if you have ice on the wires and the ice falls off the lower wire before it falls off the upper wire it would bring the lower wire right up to the other one.

Mr. W. M. Austin:* I should like to ask the speaker if he has ever noticed any permanent stretching in long spans of copper cable. I know that steel cables, especially those with a hemp core such as are used in hoisting do lengthen considerably in service.

Mr. James S. Martin: We have had trouble with only one span. There is one span which has come down several times, but I think the reason for this is that there is something wrong with the clamps and they are allowing the wire to slip. That span is not our longest by any means, and it does not seem reasonable that it is the only span which is stretching. It is not damaged, so I think it is the fault of the clamps.

Mr. S. S. Hertz:† I want to express my appreciation of Mr. Martin's paper and the very able way in which he has presented it. It is splendid information for us. It would be interesting to know the effect of corona, not only upon the tower, but also upon other parts of the structure and the conductors.

There is a positive trend to-day towards the use of long spans wherever possible, inasmuch as long spans have proved far superior to short spans in the matter of maintenance and the question of maintenance is given the foremost consideration today in weighing plans of design.

The wide and frequent change of conductor stress on short spans, which sometimes will vary as much as 100 per cent. several times a season, is far more detrimental to the strength of the conductor materials than an almost constantly applied stress even if higher in value. The stress in longer spans might vary only 10 or 15 per cent.

The matter of proper conductor metals which will permit of longer spans, has engaged the engineering profession for about

*Supply Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

†Electrical Engineer, Pittsburgh.

a half century. Perhaps one of the most notable advances in this direction has been the perfection in recent years of the molten welded process of making copper-clad steel wire whereby the copper is actually welded to the steel, making a homogeneous wire. A number of transmission lines in the West have operated continuously for ten to twelve years with this material on spans up to 4100 feet, and recent inspection has shown that they are in perfect condition.

MR. JAMES S. MARTIN: As to the first question, I am not an electrical engineer and that problem is not in my line. Perhaps Mr. Smith can answer the question.

MR. H. W. SMITH:* I should think that with the conditions in this district, and the size of conductors used on 66,000 volts, there would not be much trouble from corona. It is, however, a feature in high-voltage transmission and that is one factor that is bringing into prominence the use of aluminum steel reinforced cable, because with the larger diameter the corona loss is reduced and the critical voltage (the voltage at which corona forms) is raised. Mr. Peek, of the General Electric Company, has done a great deal of work on that subject and there have been quite a number of actual tests made on lines which fully bear out the research done in the laboratory. In view of that information I should not expect any trouble with the lines of the Duquesne Light Company.

MR. N. A. WAHLBERG: Mr. Martin spoke of the span breaking down. Is it possible that the wires had been weakened due to lightning? I recently returned from a trip to Michigan where I had the opportunity to examine aluminum wire which had been in service on a 140,000-volt line. These wires had to be removed due to individual strands breaking. Upon close examination numerous spotted places were noted where lightning had passed over the wire and crystallization had taken place. At these points any strand could be broken off with one bend.

*General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

I noticed on one of the slides an arrangement for testing suspension insulator strings, at the foot of the towers. What would this load be?

Mr. James S. Martin: I do not know what was specified on the last insulator sets, but on former insulators they had to stand an 8500-pound test before they left the factory. The test in the field was simply to see that everything is in place and all connections properly made. No specified tension is used.

Mr. L. F. W. Hildner, *Chairman*: You did not explain the method of testing towers; that is, the physical test. I remember that horizontal test they used to have, but what do they use now?

Mr. James S. Martin: They have a big frame set up facing two ways to test the tower from two sides. The tower is set up in its normal vertical position and tested. The American Bridge Company has a big frame at the works at Fifty-first Street with adjustable base connections to fit any size of tower and arranged so they can rack the tower any way they please. Equalizing levers are attached to give uniform tension at each point of application of stress. Cables are attached to these levers and, after being passed through a number of pulleys, to bring the tension down to the capacity of the dynamometer, the cable is attached to the dynamometer. Then tension is put on and sights taken with transits to determine the temporary deflection, and, after removing the tension, the permanent deflection. When the tower is taken out every hole is examined to see whether or not there is any distortion in the metal.

Mr. O. M. Jorstad: Can you give us a figure on the cost of erection of a tower, and the estimate for concrete?

Mr. James S. Martin: To be on the safe side I allow $550 in estimating for a concrete foundation, on the average. It does not run that, but that amount will take care of the average cost for our towers sustaining a turn in line of less than 45 degrees. I usually estimate on the earth anchorage for the suspension or line towers at $175. It does not cost us that, but

that will take care of accidents and other contingencies, such as wet weather, etc.

MR. O. M. JORSTAD: About how many yards would there be in a $550 tower?

MR. JAMES S. MARTIN: The yardage in a tower runs from about 11 to 20 yards. Of course that $550 includes excavation, setting up anchorage steel, putting in concrete, backfilling, tamping, and moving equipment to the next tower.

MR. C. W. KENNEY:* I should like to express my appreciation of Mr. Martin's paper. One point in particular on which I certainly agree with him is the matter of survey and profile and the advantage of a profile plotted on the same scale for both vertical and horizontal measurements. In my opinion it is very much better to have the same scale.

I would like to ask a question in regard to the assumed loading of wires. Do you believe that the immediate vicinity of Pittsburgh justifies a calculation of loading a half-inch of ice? I know we are all using it and we are classed in the heavy-load area but it seems to me that in the immediate vicinity of Pittsburgh it is not justified according to Weather Bureau reports.

MR. JAMES S. MARTIN: There were some wires broken in Ambridge a few years ago on which the thickness of ice was three inches. These were not our wires but were telegraph wires. The thickness of ice was measured by American Bridge Company men. That may not occur once in 20 years, but it is liable to occur again because it has done so before.

MR. C. W. KENNEY: Was that a general condition or was it some local condition?

MR. JAMES S. MARTIN: I can not remember the date of that storm. I believe it was somewhere about 1913 or 1914. The

*Chief Civil and Construction Engineer, West Penn Power Co., Pittsburgh.

circumstance was quoted to me at the time we were putting in the river crossing at Ambridge.

Mr. O. M. Jorstad: Along that line I might refer to a recent paper before the American Institute of Electrical Engineers by A. E. Silver* on a 220-volt line. His load is 1.5 inches increase in radius due to sleet, making a total increase of three inches so that possibly half an inch might be considered conservative.

* Proc. A. I. E. E. 1919. v. 38, pt. 2, p. 751.

LONG-WALL SYSTEM OF MINING

By R. W. McCasland*

The long-wall system of mining had its inception in the Black Band Iron Stone Mines near Airdrie, Scotland many years ago, the seam of iron stone being from two to three feet in thickness, and underlaid with a coal seam one to 1½ feet in thickness, and overlaid with slate or shale. The rooms were widened for the sake of economy, and pillars or packs built of refuse material, with the idea of replacing or supplementing the timber roof support. As the work progressed, the resisting quality of the packs was observed, others added, making a long continuous wall, and the working face further lengthened or widened to such an extent that the name "long-wall" was appropriately applied to this method or system of mining.

It was in this district, that the earlier improvements were brought about. A mine manager named James Richie is credited, by some, with having done much pioneering work in this respect. The improvements that have taken place since have been gradual, almost slow, and the adaptation of this method of mining to American coal-mines has made so little progress that the system is practically unknown in many large mining regions.

This paper will not add much to the accumulated knowledge of the subject and many important points may be passed untouched, but it is hoped that a trend of thought may be started that will eventually bring about a further improvement in the application of machinery to our mines and at the same time insure conservation of our valuable natural resources.

GENERAL CONSIDERATION OF PLAN TO BE USED

The first question that naturally arises is, when can the long-wall system be adopted in preference to the room-and-pillar method, and when can it successfully replace the room-and-pillar method of operating mines? If we can give full effect to

the merits of the system, it should be adopted for the mining of all coal seams four feet and under in thickness and in most seams ranging from four to five feet in thickness where a complete recovery of coal is one of the points of first consideration. It may be found profitable in thicker seams, especially split seams, where large beds of impurities exist in the coal seam which can be used for pack material. When the system is thoroughly established, the mining costs would be lower in each case, and a larger percentage of lump coal should be obtained. The above, of course, are general statements. The more detailed advantages and disadvantages will be apparent from a further consideration of the subject.

The long-wall system of mining has been properly classified into two distinct divisions; that is, long-wall advancing and long-wall retreating, and it naturally follows after the long-wall system has been given consideration that we are called upon to choose one or the other of these subdivisions. In the former, the workings are advanced from the mine opening toward the boundary line of the property and, in the latter case, the main entries are driven to the boundary of the property and the principal workings are worked back toward the mine opening. The main feature of either method is to remove practically all of the coal as the working face advances and to maintain the exposed roof for a time by the use of pack walls built from waste material and material secured by enlarging the roadways. Cribs and mine props are also used, but the principal support is obtained from the pack walls. The pack walls also form in time a permanent support along the haulage roads and principal air courses in the advancing system. The last mentioned are known as road packs and any packs used in the areas between the roads are known as gob packs.

In reviewing opinion pertaining to the two long-wall systems, we usually find the following advantage on the side of long-wall advancing: A minimum of capital expenditure for mine development, and the short time required for quickly developing sufficient coal area to insure production for a very large mine. This time element is a very important consideration where a very large outside mining plant has to be built and deep shafts have to be sunk before any coal development is obtained.

We usually find that other advantages are attributed to the long-wall retreating method. Among the reasons advanced are: A greater percentage of minimum recovery; a better control of roof, ventilation, and drainage, with less liability to gas and dust explosions; a lower cost of maintenance of permanent roadways and air courses; a smaller timber consumption, and a larger output from an equally developed area at the face

The above are the usual advantages attributed to the two systems, and they appear to be almost overwhelmingly on the side of the retreating method, especially when viewed from a purely engineering standpoint. Enginers often, with some justice, criticize methods which are adopted by operators in the belief that the method is better suited to the financial condition of the operator. These methods are also criticized by accountants and economists as being poor policy in the end. However, the merits of the particular point can be reduced to figures with some degree of certainty, and the lay-out planned best to suit the physical condition of the property while keeping in mind that the primary object of operating coal-mines, is to make money. It is well to keep in mind also, that as time rolls by American coal-mining companies are bound to face competition of a strong and capable kind, and that generally the work should be planned with the assumption in mind that the operating company has sufficient capital or credit to insure the adoption and perfection of the most economical methods.

Even with the assurance of abundant capital, it would not be wise to accept the above enumerated advantages and disadvantages without giving very serious thought to the physical condition of the coal seam and its underlying and overlying strata, especially the roof strata; as after due consideration it may be found that unless ideal roof conditions prevail, permanent roadways and air courses may be more expensive to maintain in the retreating system than in the advancing system, for the reason that there is a peculiar arching and locking action on the roof immediately over the roadways and their heavy supporting packs. The advantages as to maximum recovery will be so slight as to be almost negligible, and the greater liability as to gas and dust explosions will

not be sufficient in most cases to cause much concern in the choice of the two systems.

ROOF CONTROL

The roof control and the utilization of roof pressure will be given consideration next for the reason that in long-wall workings, it is by far the most important point for consideration, and, in thinking of roof control, it is well to remember that the roof cannot always be controlled and that it would not always be profitable to control a roof in an absolute sense. More often, the practical control will be in the nature of a successful retreat rather than a positive resistance. Assured a practical roof control, we can take up the other phases of the engineering work with a greater degree of confidence in the planning of haulage roads and air courses. Drainage and ventilation will require only the application of well-known principles and practice, and assurance may be had that the mechanical requirements will be easily taken care of by our mechanical engineers. Before adopting a method for the control of roof and the utilization of roof pressure, consideration must be given to the cleavage lines or cleats in the coal seam; the direction in which they run; whether there are pronounced or incipient lines of cleavage in the roof overlying the coal, and whether the cleavage lines in the roof run in the same direction as those in the coal; the nature of the roof itself, as to whether it is of a bending, yielding nature, as shale, slate, and some kinds of sandstone; or whether it would snap abruptly as in the case of limestone. The nature of the floor should also be considered as to whether it is of a hard, firm structure or of a soft nature which will heave or crowd easily when subjected to pressure. The materials for the control of roof, aside from the coal seam itself, consist of ordinary mine props, timber for cribs, and rock or earthy material, obtained from the coal seam or from the roof and floor of the seam. The object, of course, is to maintain permanently openings for haulage roads and air courses, and to maintain temporarily space at the working face and such temporary roadways as may be necessary for the purpose of gathering the coal to the main haulage system.

There are two general methods employed in roof control. One method is to build packs of sufficient strength to insure a gradual subsidence of the roof over the mined area and when this method is employed it is desirable that the roof measures yield or bend rather than break abruptly. The other method is to build pack walls where necessary for the future protection of the main haulage roads and air courses, and to use cribs for supports in the mined area, between principal roads and along the face, to support the roof of the mined area for such a length of time as to prevent falls from interfering with the working face and the mechanical means of removing the coal from the face. As the face advances, the cribs can be removed from the back or first row and brought forward to the face and used again. As this system progresses, falls will occur in the area from which the cribs have been removed.

The latter method might be called a caving method, while the former might be called a supporting method. The former will insure a better method of control in most cases especially in the advancing system, and might prove desirable in retreating work in some places.

If this method is desired, and the seam itself does not provide sufficient waste material for the building of packs, consideration must be given as to where the additional material shall be obtained; that is, whether it shall be lifted from the floor of the roadways or be brushed from the roof. The nature of the material thus obtained will govern to some extent the method adopted. As securing additional material will in most cases require heavy blasting, and as it is desirable that the sides of the roadways be left as smooth and straight as possible, it will be necessary to set break lines of timbers along the sides of roadways before the shot is fired. The ease with which the hole for the shot can be drilled is also an important item in cost. Where the material is obtained from the floor, the natural roof is not shattered by the blasting operation and no high cavity is left where gas can accumulate.

This method has the disadvantage of interfering to some extent with machine operation; also, it is not as desirable from a drainage standpoint, but generally is to be preferred where the

floor is of soft material and where a smooth, sound, natural roof is present above the coal. Obtaining the material from the roof has the advantage of leaving a smooth mine floor, which is more favorable to drainage and also to permanent roads, which after having been gone over a second time show the advantage of an interlocking and arching effect which very materially reduces falls. By the extensive use of packs in this method, cribs for the support of the working face will not be required except in extreme cases.

By following the caving method, and using cribs where conditions are suitable, it will be found that a very considerable saving in the cost of operation has been effected. This will be true particularly in the case of retreating work and in some instances in the case of advancing work. In the use of either method, it will be found that the application or the removal of supports is largely a question for experienced practical judgment.

In the long-wall method of mining, it will be found in most cases that roof pressure can be used practically to an advantage in bringing down the coal after mining and that the use of explosives can be minimized; and it will be found, usually, that by advancing the faces in a certain direction with respect to the cleavage lines of the coal and roof, and also with respect to the dip or inclination of the seam, better results can be obtained than in the case of the face being advanced in any other direction. The object is to obtain a large percentage of lump coal with a minimum effort. Consideration should also be given to the direction in order that the undermined coal will not fall in a mass and require a large amount of manual labor to break it up sufficiently for loading purposes.

Experience should be the guide in matters of this kind, but it appears to be a well recognized fact that a greater pressure will be exerted on the coal when going to the dip than to the rise; also that the most critical time with respect to roof control and pressure is when the working face has gone into a dip or swale and has just started to the rise. A little consideration will show that the line of pressure on the coal will change rapidly and that the inverted natural arch in the roof will require extreme measures to hold it in place.

Fig. 1. Section of Mine Map.

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With respect to the use of timber in work of this kind, ordinary mine props will be required for temporary protection at the face, and may very often be removed later and used again. It is important, however, that no mine posts be included within the area of a pack wall. The timbers used for cribs in the supporting method where a gradual subsidence is desired, need not be of first quality and, in fact, timbers that are somewhat decayed, such as old railroad ties, make a much better support than new timbers, for the reason that they yield to pressure and do not produce a shear in the roof. The timbers used for cribs at the face with the intention of removal, as in the caving method, should be sound, hard timbers of a size that can be conveniently handled by one man and any cushioning of the cribs should be taken care of by other means. Roof pressure can be controlled to some extent at the working face by working an offset or stepped face where the mining is done by hand; but, in the case where machinery is used, a long continuous face is desirable and the stepping in the sense referred to above would be a very great disadvantage. The action can be controlled to some extent by stepping the machine sections and by varying the general direction of advance.

NOTES FROM EXPERIENCE

It may be of interest and profit to study the experience of an Eastern Ohio long-wall operation. At the mine referred to, the long-wall method has not been in use since the start of the mine. which is a very old mine and is mining the Freeport seam of the Allegheny series with an average thickness of three feet, eight inches, having a hard fire-clay bottom and a shale roof, at times mixed with thin sandstone beds. The long-wall method was started in June, 1913. Fig. 1 (folding plate), from a section of the mine map, shows the starting place of this work and the progressive advance of the face as shown by different survey dates.

The method was attempted at this mine to secure a greater concentration of mining area and to make a complete recovery of the coal seam. The location selected for the start of this method was not ideal, but was not, strictly speaking, unfavorable to the method. The main haulage road was dipping nearly one per cent.

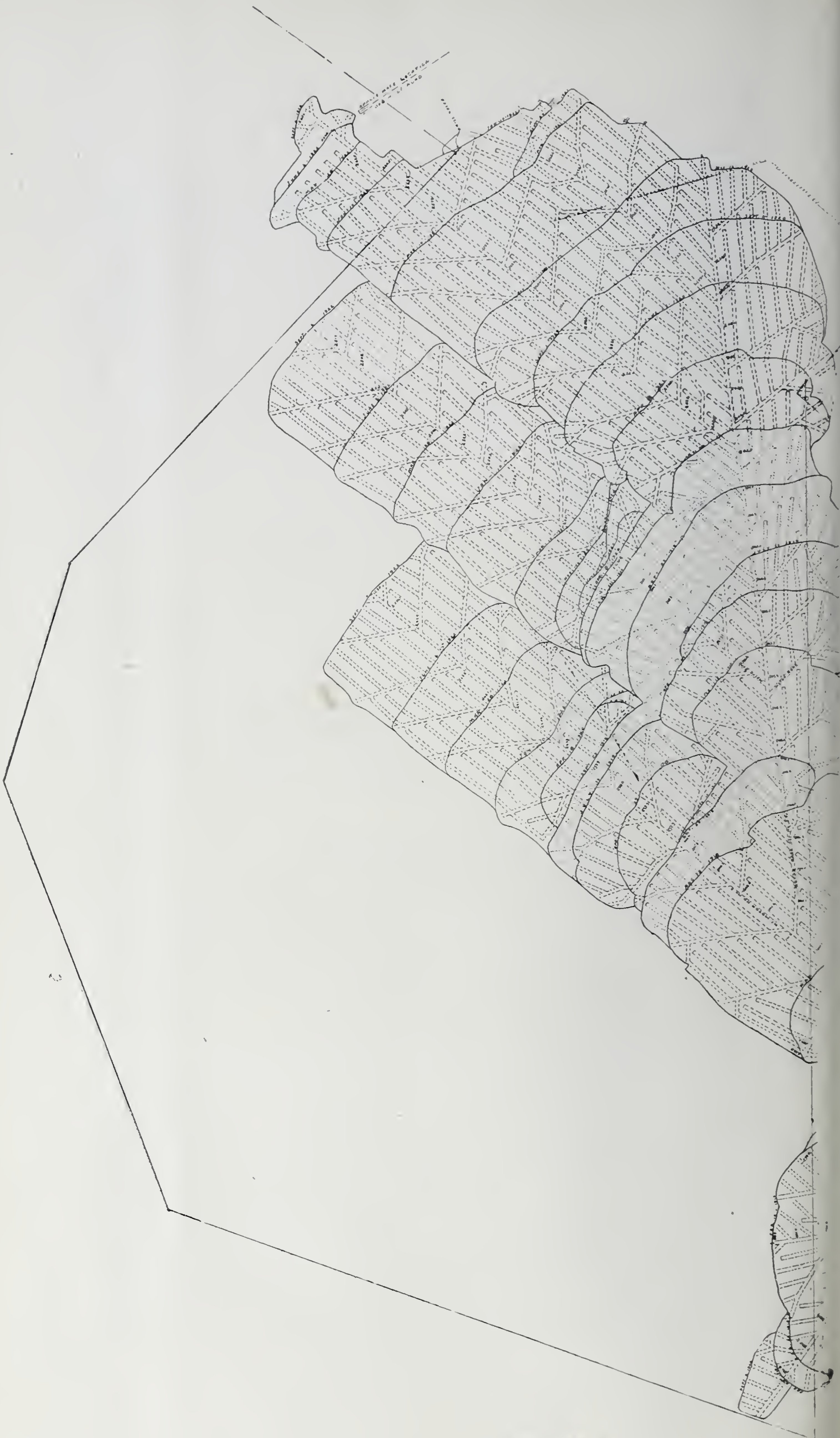

Fig. 2. Section of Mine Map.

and a haulage road to the rise would have been preferred, if possible. The system started and still in use, as will be observed from Fig. 2, which is reproduced from another section of the mine map, is the Scotch or 45-degree long-wall advancing system.

The coal is mined by continuous cutting, electrically driven, long-wall machines which with an over-supported cutter bar enable the operator to cut the coal with a perfectly smooth floor, adding considerably to the speed and comfort of the miner when shoveling coal.

Fig. 3 and 4 show a machine in operation, operating on

Fig. 3. Coal-Cutting Machine.

skids which have since been abandoned in favor of a double-bitted chain which successfully cuts the coal on the bottom. The machine undercuts from 3½ to 4 feet, is reversible, and the usual amount of work for an eight-hour shift consists of cutting the entire face of a machine section which has one central motor road with six ordinary roadways on either side spaced 42 feet from center to center making a total working face for the machine of 546 feet. The machines are operated on a tonnage basis, the

rate of pay being exactly one-half the usual breast-machine rate.

It will be observed from Fig. 1 and 2, that the ordinary roadways are usually cut off by 45-degree roads spaced usually about 200 feet apart, which in this mine are called "slope roads." The

Fig. 4. Coal-Cutting Machine.

main motor roads are made about 11 feet wide where required, and the ordinary roadways eight feet wide. The material for supporting the roof is in most cases obtained from brushing the roof, the usual carry of brushing being equal in thickness to the thickness of the coal seam. The material thus obtained is built in pack walls along the roadways, with well built walls along the roadside and along the face; the remaining space at the walls is filled with loose material and so constructed that the pack will offer greater resistance on the roadside than on the waste or goaf side.

Fig. 5 gives some idea of the road arrangement and the area of roof supported by pack walls and also shows in some detail the method of building the pack walls and turning the roadways.

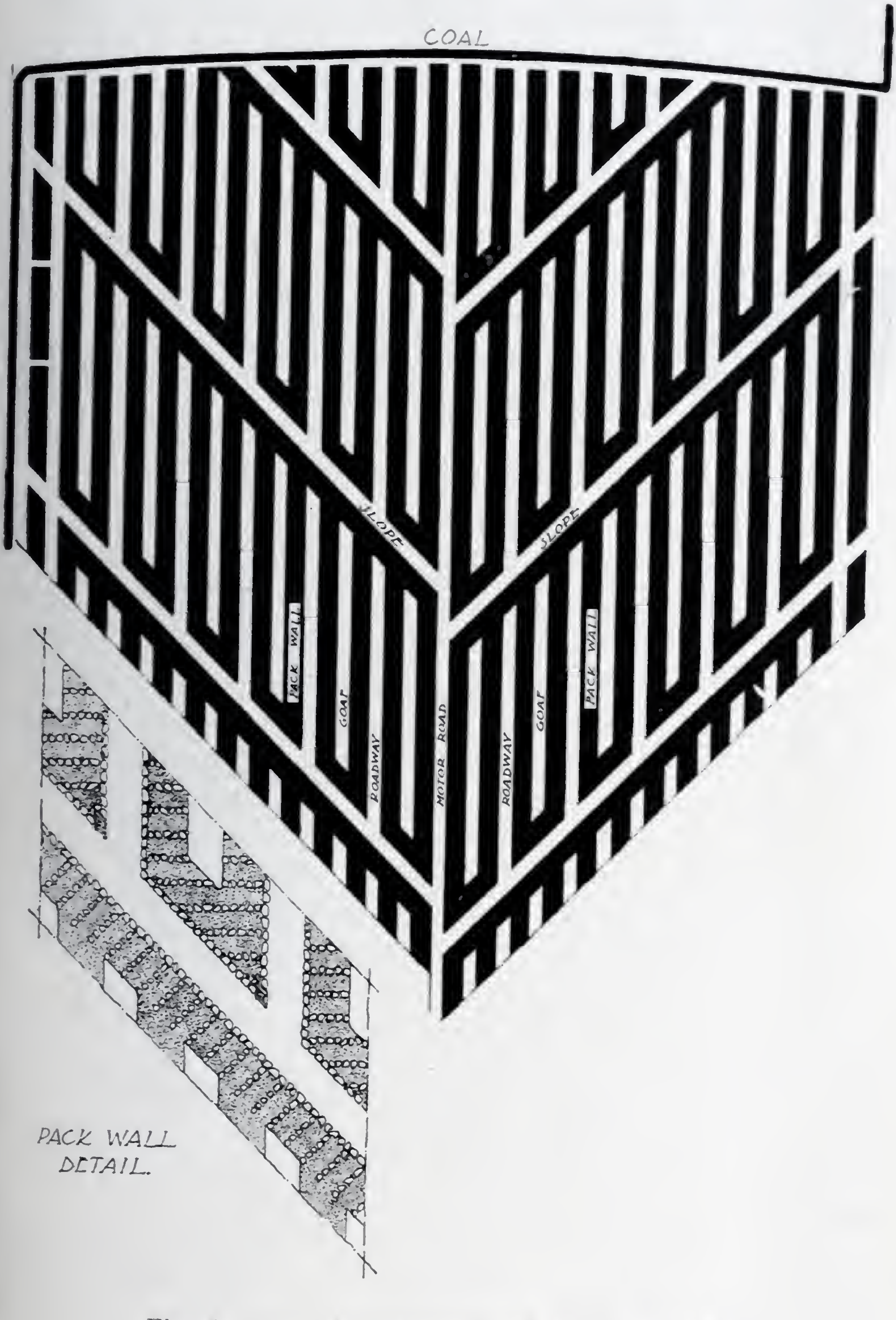

Fig. 5. Road Arrangement and Roof Support.

Note the timber cribs at the points of pack walls and the break-throughs in the pack walls or buildings at the left of the illustration. These are called split buildings in the mine, and are essential to ventilation at the extreme end of the ventilated face; as, otherwise, gas could accumulate between the pack walls and the coal rib.

Fig. 6 gives a relative idea of roof subsidence in this mine.

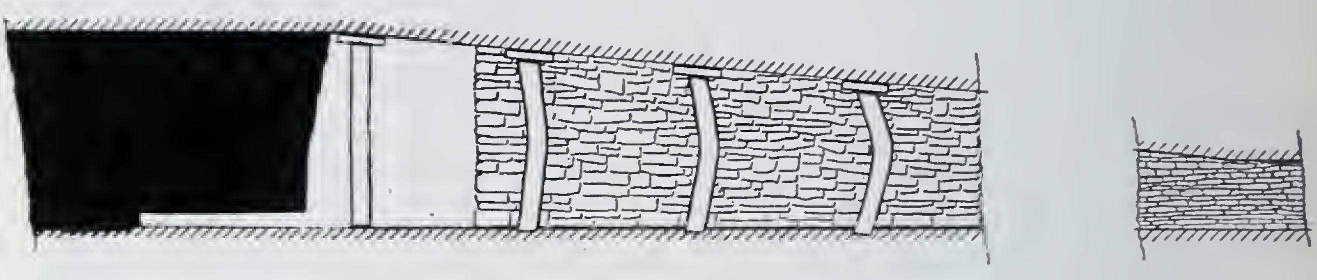

Fig. 6. Roof Subsidence.

It is generally considered that, when the roof has subsided to such an extent that the pack wall is reduced to about one-third of its original height, complete subsidence has taken place and the main haulage roads or air courses can be rebrushed with the assurance that very little additional work will be required in the future.

Measurements were taken in a very old place, which showed that where the original height of the seam had been three feet, four inches, and the original height of the roadway had been seven feet, complete subsidence had reduced the packs to 20 inches in height while the space between the roof and the bottom in the middle of the goaf had been reduced to 13 inches. The height of the roadway had been reduced to five feet, four inches. This probably represents an extreme case of subsidence. The point where pack walls have been reduced to about one-third of their height usually follows at a distance of about 200 feet from the working face when the face is in continuous operation. If for any reason a section of the mine is stopped for a considerable period of time, this complete subsidence approaches very nearly to the face.

We might add here that this mine is usually in operation during every working day in the year, but owing to dull business during 1921 the mine was idle from February 24 to September 16. During this period there were no falls of consequence at the

face and it was comparatively easy to get the mining machines across the face when operations were resumed. However, as might be reasonably expected, the advance of subsidence caused the slopes and roadways at the face to be partly closed and it was necessary to do a considerable amount of brushing in order to get the mine cars to the face.

To get some idea of the cost of cleaning up falls, brushing, and retimbering after this long shut-down, it was ascertained that the total expense of this work which was all that was required to put the mining sections in shape to produce 18,000 tons per month, was $1035. It would have cost many times as much to have maintained or opened up sufficient working places to have produced this tonnage under the old room-and-pillar system.

In the operation of this method ordinary mine posts are used at the face and set in line following the mining machine at a distance approximating nine feet. After the coal is removed by the loader, he is required to set an additional post, with the result that there is a row of posts for each machine cut, at practically 4½ feet from center to center. As work progresses, a great many of these posts are recovered and used again. Some posts are left until bent or broken when it is desired to steady the roof in waste spaces.

When this method of mining was introduced in this mine, it was new to a large majority of the workmen and was viewed with the usual amount of suspicion. The working face developed rapidly and considerable difficulty was experienced in getting men to work on the coal face; first, for the reason that they were somewhat dubious about the safety of the roof, and secondly, because they were not used to mining coal in the small space afforded by this method. The average day's work for a machine loader in the room-and-pillar system was nearly eight tons a day. It was confidently expected by the management that a loader would load 10 tons a day in the long-wall workings as easily as he had loaded eight tons in the rooms, and the tonnage rate for loading coal was fixed at 9/11 of the usual loading rate. It required a few months to train loaders so that they could load eight tons a day in the long-wall workings and it required practically 18 months before the men became so accustomed to the work that they laid aside

their prejudice and loaded coal at the rate of 10 tons a day and over. But from that time on until the beginning of the year 1920, a gradual improvement was shown as indicated by the tons per man average shown below:

Year	Tons	Year	Tons
1916	10.02	1919	12.57
1917	11.25	1920	14.38
1918	12.24		

It might be added that during 1920 there was a shortage of men at this mine due to the competition of other high-paid lines of work, and that the loaders remaining in this mine were all dyed-in-the-wool miners who would not work at other lines of work and that they were given all possible assistance in maintaining their high output per man. During the most recent operation, the average output per man has been from 12 to 13 tons which is a conservative figure and insures cleaner coal in the mine cars. It is evident that the loading wage at this mine could be adjusted without injustice to the loaders when their daily earnings are compared with other operations. The usual time allowed for brushing the roof of the roadway and building the packs, which includes drilling the hole if the material can be drilled by hand, is four hours each to two men. This time can be improved upon by a few very rapid workers, but that is the exception rather than the rule. Usually the roof is so hard that a machine auger is required. One of these outfits is shown in Fig. 7. These outfits usually drill eight or nine 7-foot holes per shift. With respect to the safety and accident experience at this mine, the fatal and serious accident record is very much better at the face since the adoption of the long-wall method. In fact, a fatal or serious accident has not occurred at the working face. Minor accidents, such as cuts and bruises on hands, feet, and legs, have increased very considerably. The latter is no doubt due to the smaller space and close quarters in which the men are required to work.

The experience with respect to mine fires is that on one occasion a break in the roof opened to such an extent that gas came down from a small seam of coal which at that point was 8 or 10

feet above the main seam of coal and, becoming ignited, in turn ignited the small seam of coal. The method employed in fighting this fire was to reduce the volume of air at that point and proceed with the working face as rapidly as possible. In a short time the creeping subsidence completely snuffed out the fire. Their experience with gas in this method of working, has been fully as good as in the room-and-pillar method, if not better.

Fig. 7. Machine Auger.

One incident that may serve to illustrate a very necessary point of caution to be observed by those opening out long-wall workings occurred sometime after a mining-machine section had started, after a considerable period of suspension. The face moved in such a direction that caving took place in the roof measures, very much like that experienced at the outset of the operation—that is, the lower roof measures settled abruptly on the packs and left an overlying space which filled with gas. As the work progressed, the upper measures again took a fall or seat,

with the result that the gas was forced down a very small break near the face. It became ignited and caused considerable commotion and several minor injuries but no fatalities.

During the past year, an experiment has been conducted at this mine in the use of a belt conveyor for transporting the coal from the face to the mine cars. A general idea of the system in use or contemplated is shown in Fig. 8. A sectional belt con-

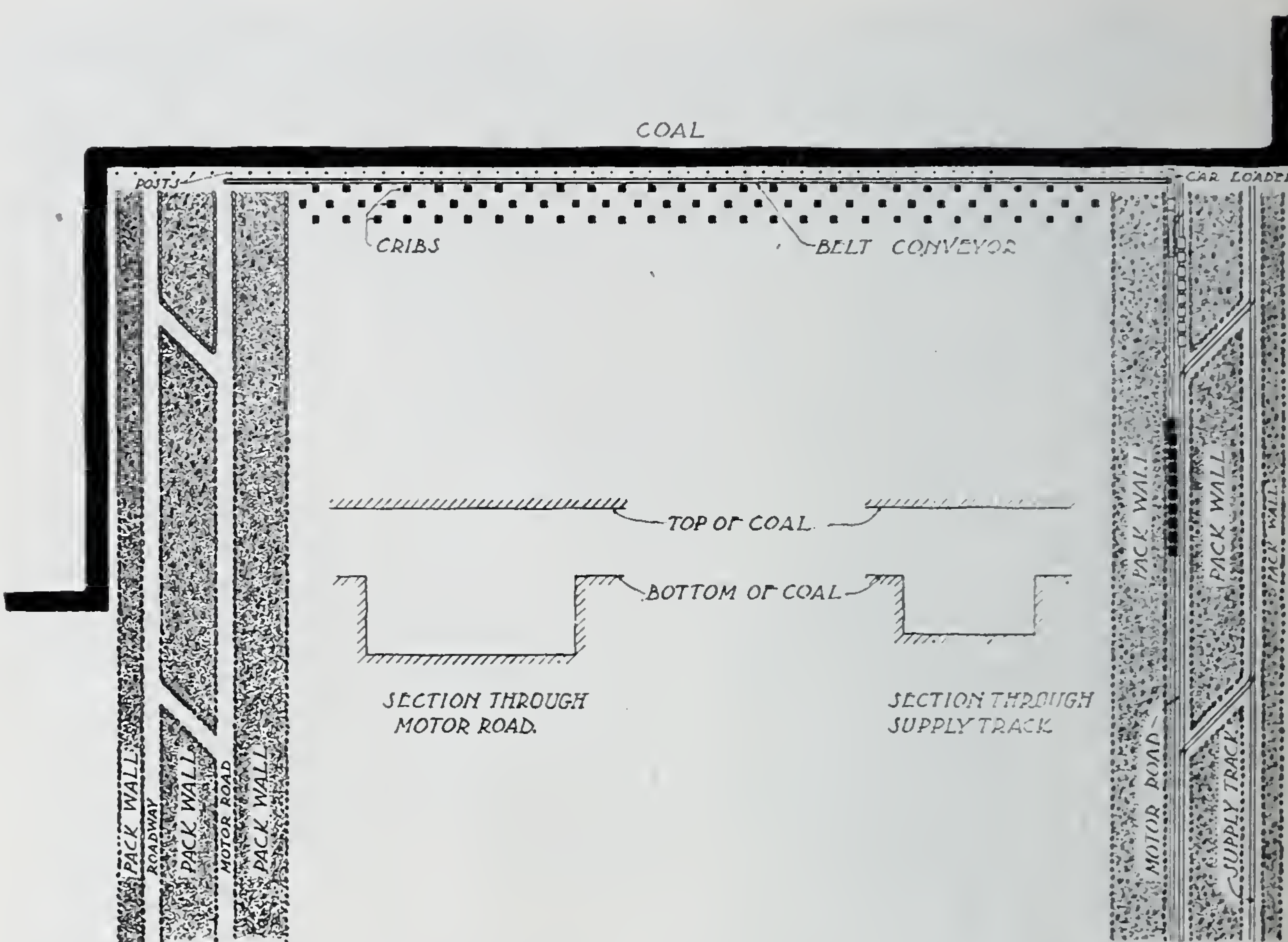

Fig. 8. Long-Wall Machine Section with Belt Conveyor.

veyor 30 inches wide is used to carry the coal from the face to a loading conveyor which in turn conveys the coal to the mine cars. The sketch shows the method of transferring the cars past the discharge point of this conveyor and the method of handling the cars. Cribs four feet square built of eight by eight hardwood timbers are used to support the roof at the face a sufficient length of time to protect the machinery, after which they are withdrawn and the waste area allowed to cave.

The system has not been entirely perfected, but enough work has been done to show that the face can be maintained and worked

economically when kept in continuous operation. It has been ascertained with certainty that a loader can load 25 tons of coal on the belt as easily as he can load 12½ from an ordinary roadway into a mine car, and this figure may be surpassed when men become more accustomed to the work. Compared with the other system in use in the mine, it will be observed that at least half of the loading time can be saved and that the machine time will be the same for a 500-foot section; that it will require six men to brush the roads, and move the cribs ahead on one shift and that on the next shift the same six men will be required to move the conveyor forward. So that aside from the loaders and machine men, the day men employed will be one timber man to follow the mining machine, and six to build cribs, brush roads, or move the conveyor as the case may be. It will also require two men to take care of the back brushing and other up-keep work about this system of mining. While the coal is being loaded, it will require one face or section boss to look after the general safety of the section and it will require two men to shift the mine cars at the loading point. The number of men employed having been outlined, the cost of operation can be ascertained by applying the usual scale of wages.

LAYING OUT AND OPENING LONG-WALL MINING

A great deal has been written on this phase of the subject and most books on mining give a very good general idea of the methods usually employed in laying out long-wall mines. An example of the Scotch long-wall system in this country often referred to is that of the Spring Valley Bituminous Collieries Company, in Bureau County, Ill. For anthracite practice, the Bull's Head Anthracite Collieries Company, Providence, Pa., and for a triple conveyor system, that used in the Vinton Collieries, Pa., are examples. This subject will not be treated generally, but brief mention will be made of two important points to be observed from an operating standpoint.

1. A roadway or air course through advancing long-wall workings, which is to be maintained for a period of

years, should never be located near a coal rib for the reason that the settlement is not as complete and shearing action near the coal rib causes frequent falls and a high maintenance cost.

2. From the standpoint of local drainage, a long-wall face should not be driven directly to the dip or rise, but the working face should have a pitch to one side which will allow the water to accumulate at one side of the section and greatly reduce the piping and pumping expense.

CONCLUSION

Referring to the previous statement concerning giving full effect to the merits of the long-wall system, it should be observed that the full effect cannot be expected until the management and men have become thoroughly accustomed to the system.

Many experiments started in American mines by inexperienced managers with an insufficient supply of skilled labor, have resulted disastrously. This, however, should not deter mining men from giving full consideration to the merits of the long-wall system of mining, but should rather serve as a warning that careful preparation should be made and all details thoroughly considered, including the source of labor supply. If careful planning and good judgment are used, the system can be adopted with full assurance that satisfactory results will be obtained as regards safety, profit, and conservation.

DISCUSSION

Mr. G. B. Southard:* We have been experimenting in order to develop our system for long-wall conveyor mining, but this has been carried out to such a small extent that I am not in a position to give much of a description at the present time. We are now using a modification of the conveyor system shown by Mr. McCasland excepting that instead of one long face we have two short faces each 100 feet long. There is a conveyor laid along each face; one traveling to the right and the other to the left, and these face conveyors discharge onto a central haulage conveyor which is laid in a heading driven at right angles to the faces. This haulage conveyor carries the coal to the side track and discharges into the mine cars.

We are using the caving method entirely, making no attempt to hold the roof except at the working face. Our roof conditions are such that the top would break rather than bend and subside so we endeavor to get a roof break about ten or fifteen feet back from the face. As the work advances and the conveyor is moved forward, timbers are set immediately behind the conveyor and the last row of timbers farthest from the face is moved. So far we have been successful in having the roof break at the last line of timbers, but we realize that our work has not yet passed the experimental stage. After we have made sufficient progress so that a description would be worth while I shall be very glad to give it to this Society if you would be interested.

Mr. Andrew Orr Bain :† I am sure Mr. McCasland is to be congratulated on his paper. I have known him for a few years and know something of the long-wall system which he has had charge of at Steubenville.

In my 20 years' experience in long-wall mining in seams varying from 17 inches to five feet, six inches in thickness I have seen the following cutting machines used: disk, rotating bar, and

*Chief Engineer, West Virginia Coal & Coke Co., Elkins, W. Va.
†Coal Inspector, Duquesne Works, Carnegie Steel Co., Duquesne, Pa.

chain. These were used for undercutting the coal, the undercutting varying under different conditions from three feet, six inches to five feet in depth.

It is a pleasure to hear that Mr. McCasland has now adopted a belt conveyor in his mine and I am confident that it will take only a short time to prove the advantages to be gained through its use. Among these will be a larger percentage of lump coal, cleaner coal, and reduced cost of loading.

The long-wall system has great advantages over the room-and-pillar system in that the maximum output desired can be obtained in a much shorter period. Other points in its favor are the total extraction of coal in the first working; the reduced cost of timber; the concentration of the working face, and the reduced amount of trackage. Furthermore, the air passes along the working face so that the miners are always working in a fresh current of air. With suitable conditions, face conveyors will always prove a great advantage.

There are many types of conveyors which have been used with success in long-wall mining; among these are the belt conveyor, the trough conveyor, the Gibb carriage conveyor, and the Thompson slip conveyor. In each of these cases the brushing or ripping of the haulage roadway is done in the floor and the conveyor loads directly into the mine cars. I feel confident that Mr. McCasland will find the conveyor section a great improvement over the old system of having a roadway every 42 feet in which case the coal was shoveled along the face to the roadway and then into cars.

My experience in England and Scotland with long-wall faces has been somewhat similar to that shown by Mr. McCasland. We had long conveyor sections with only one roadway at each end of the conveyor face. We used four rows of posts (staggered), at all times withdrawing the row of posts next to the gob (or waste) as soon as another row was put up behind the machine at the face, just leaving sufficient room for the machine or conveyor between the coal face and the last row of posts. By this arrangement the weight is always kept moving forward on the coal face and, by spragging the coal after the machine, the coal breaks off at

the back of the undercut so that very little explosive is required.

Another point to be considered is the friability of the coal, as by driving the face in a certain direction to the cleavage of the coal the results can be greatly improved..

It seems to me that the time is ripe in Pennsylvania for the development of the thinner seams by the long-wall method of mining, but someone with long-wall experience should be put in charge or the operations may prove a failure.

Regarding the subsidence caused by the long-wall method, it is quite different from the results caused by the taking out of pillars. The subsidence is quite gradual and regular. Let me give two illustrations: We took the coal out completely, by the long-wall method, from under a house in which we lived. The walls cracked somewhat but, as the working face advanced, these cracks completely closed to the extent that you could not put the blade of a knife into them. In another instance three miles east of Glasgow, Scotland, the main coal seam which had been worked many years before by the room-and-pillar method was flooded for miles. A shaft was sunk above the outcrop of this seam and passed on to the Kiltongue seam about 200 feet below. This 200 feet of intervening strata was composed mostly of sandy shale and sandstone. The Kiltongue seam, which varied from two feet, six inches, to three feet in thickness was worked by the long-wall method under this area of old workings which were flooded with water and there was no trouble experienced from the overlying water.

Mr. W. A. Weldin, *Chairman*:* Mr. Southard, what type of conveyor are you using?

Mr. G. B. Southard: We are using a type of conveyor which is not yet on the market—one that was especially developed for this class of work. It is a modification of the apron type and is made up of steel pans carried on rollers running on a structural steel frame. The frame is made in six-foot sections and a conveyor can be assembled with a length in any multiple

*Blum, Weldin & Co., Pittsburgh.

of six feet. All parts are made to be easily connected and disconnected, so that no difficulty is encountered in the mine in lengthening or shortening the conveyor as desired. It is of light construction and can be readily moved or transported.

It is electrically driven using a drive chain which engages a lug on the bottom of the pans. The driving unit is made complete in a six-foot section and this driving section may be placed at any point in the conveyor as it is the same length as the main sections.. As many drive sections can be placed in the conveyor as may be required so that it is possible to have the total length as much as 500 or 1000 feet. The longest conveyor we have at the present time is 300 feet, in which are three drive sections placed 100 feet apart. We have found under actual operation that these three driving units work satisfactorily and the total load seems to be evenly distributed among them. We are using about 1500 feet of this conveyor along the faces and in the haul ways, and as the operation has been satisfactory we are now proceeding to develop an all-conveyor mine. The plans are for an output of 1000 tons a day to be handled entirely without mine cars, the coal being taken from the face to the tipple by conveyors.

Mr. J. W. Paul:* The paper presented by Mr. McCasland has been of much interest to me and there are several questions I would like to have him answer.

What is the nature of the overlying strata, not only immediately on the coal but up some 50 to 100 feet? What is the actual depth of the cover? In regard to the use of the conveyor, is the coal clean or is it necessary to remove any material? If any is removed, is it done in the mine or on picking tables on the outside? I understand that is one of the conditions under which some people claim they have not been able to use the conveyor successfully, on account of the impurities in the coal.

I have had the opportunity of examining a number of longwall operations, especially in Illinois, and there the system used seems to be most admirable. I do not know what the experience

*Mining Engineer, Pittsburgh Experiment Station, U. S. Bureau of Mines.

has been after several months suspension of operations in the recovery of the mine. In Oklahoma a somewhat similar plan of long-wall operation with the use of the conveyor has been tried, and in a number of mines in which the long-wall system has been tried with conveyors on account of the suspension of the operation over a short period of time the roof has sheared near the face of the coal, and in some cases conveyors have been covered and lost under heavy falls; whereas if the work was continuous no trouble was experienced.

Mr. R. W. McCasland: Concerning the overlying strata, the coal seam in this mine of which I spoke is overlaid with about 17 feet of sandy shale. At times there are streaks or fine beds of sand. Above that is about 25 feet of sandstone. Above that are a number of thin strata, principally of a fire-clay nature, so that the first 40 feet is, first, 17 feet of sandy shale, then sandstone. As to the total thickness of the cover, the shaft is 200 feet deep and it is located near the river. The usual cover is about 500 or 600 feet; at times 700 feet.

There is a very hard band in the coal about 6 to 10 inches over the bottom, varying from one to two inches in thickness, but aside from that there are no great impurities in the coal. This band is picked out by the miner and thrown back into the waste and at times used to help pack the walls.

Mr. G. B. Southard: How long is that belt conveyor?

Mr. R. W. McCasland: As shown in Fig. 2, the top section where the belt conveyor starts, is about 400 feet long. I intended to widen that out to 500 feet from center to center, but did not do it for operating reasons. This mine was in full operation during the last strike, running to capacity all the time, and, without going into details, to have extended the belt at that time would have resulted in a reduced tonnage. We thought best not to extend it until a more favorable time. There was nothing whatever connected with the operation of the belt or the control of the roof that was discouraging. We were not able to advance as rapidly

as we wished but we did succeed in advancing at such a rate that I at least feel sure it is an entirely practicable operation.

We had thought of running the conveyors both ways to a central loading point but we found in laying out the work that when the time came to advance the machine we would have to disconnect two conveyors, move the machine, lift the rock out of the roadway about 12 feet wide and 3½ deep and 7 long, building pack walls on the side and moving up the machine and connecting the sections of the conveyor to the machine; and we thought that was too big an undertaking for the time available, which would be one shift. We may be able to work that out. That was our reason for running the belt one way instead of having two belts—to be sure to be able to make the shift in one night, from the time the men left at night until they came around the next morning.

Mr. W. A. Weldin, *Chairman*: Was that conveyor a unit or in short sections?

Mr. R. W. McCasland: It is made in 50-foot sections. The pins do not run through the entire width of the belt, but are only pinned on the side, which allows the belt to form a trough. Those 50-foot sections of belt weight about 200 pounds each, and when rolled up they can be conveniently moved between the props in moving the conveyor ahead. One man can roll it up quite easily and two men can couple it up very rapidly.

There is no frame-work excepting for the head-frames and a short frame at the foot. The supports are independent pedestals. The center of the top rollers is 16 inches over the base. These have a base of about 32 inches and they have sufficient support so there is no particular difficulty in keeping them in position unless an unusually large lump of coal gets on the bottom strand of the conveyor, and that has been overcome by putting a small bar across the conveyor to throw large lumps off the belt.

Mr. W. A. Weldin, *Chairman*: You have in the conveyor section comparatively few roadways compared with the usual section, and the building of pack walls is very much reduced.

MR. R. W. McCASLAND: There are really only two roadways in the section, the main roadway 12 feet wide requiring extra heavy packing, and a roadway at the foot of the conveyor. You do not need a track in that roadway except a small section to move the machinery ahead. We think in time it will be necessary to have cross-roads between these two roadways as they are the main air ways and it will be necessary to have a cross gate to make sure that the air current shall not be seriously interrupted.

MR. NEWELL G. ALFORD:* I would like to ask Mr. McCasland if his loaders do any other work besides the actual loading of coal. Then some of us could get a better comparative idea if he will tell us the number of man-hours per ton that apply in loading, day work, cutting and gathering. Mr. McCasland might also give us the powder and timber consumption per ton and the capacity of his mine cars.

MR. R. W. McCASLAND: They are required to set additional posts along the face as they remove the coal. The timbermen follow the machine and set posts about every eight or nine feet and the loader is supposed to set the additional posts, which is not very much work. In addition to that, they have to drill and shoot the coal where necessary, and there is a little of that work required. I would say that it is a reduction of 75 per cent. from what it is with room-and-pillar mining. It is only occasionally that they put in a shot; not enough to interfere with the man working in the next face.

As to the timbering, I do not know that I have any exact figures in comparison, but I judge it is about 75 per cent. The loader is supposed to relay the track, although the section boss may give him a little help in a difficult situation. The face is cut 3½ feet at a time and he may have a pair of rails that will not fit. If the rails are the right length he is supposed to relay them. If the rails are close to the face and the mining machine

*Engineer, Howard N. Eavenson & Associates, Pittsburgh.

comes along it would interfere with that, so the last pair of rails is generally a short pair and the loader is required to lay those.

When you get a real miner loading coal he is going at it as hard as he can and he is going to produce results much above the average loader. As long as the mining scale is attractive it will attract as loaders men who are not experienced, which will have the effect of reducing the mine average. It is desirable to keep it down, for if you do not and there are any impurities in the coal you will get them.

Mr. Newell G. Alford: Did you find any antipathy on the part of the men when you first installed the conveyors?

Mr. R. W. McCasland: Some, but not to the extent we did when we started the long-wall system. All the actual antipathy arose from the desire to keep the men on the day-work basis. Most of our loaders, are receiving about 74.5 cents a ton and making from $9 to $12 a day, and they are not at all anxious to go on day work at $7.50.

Mr. J. W. Paul: What percentage of the material removed in brushing is brought to the surface?

Mr. R. W. McCasland: None whatever. It is entirely used in the packs.

Mr. J. W. Paul: There are a number of long-wall mines where a large percentage of the material is brought to the surface. What is the ratio between the number of loaders employed in the mine and the number of day laborers?

Mr. R. W. McCasland: Three to two, perhaps. I would rather think of that before answering.

Mr. J. W. Paul: What effect does the long-wall method have on the surface under which you have mined coal? Is the subsidence manifest?

MR. R. W. McCASLAND: Not that I know of. The surface is rather rough and I have never heard of any one being able to locate a subsidence on the surface.

MR. J. W. PAUL: Do you work under streams or bodies of water and have you had any inflow of water?

MR. R. W. McCASLAND: Yes, we start at the river and under river hills. Any time we have had a flow of water it has soon been shut off completely by the advance of subsidence.

MR. J. W. PAUL: Is the surface owned by the operating company?

MR. R. W. McCASLAND: No, the coal is owned in fee and I think there have been no springs lost or any visible damage on the surface or we would have heard of it.

MR. J. W. PAUL: Is the surface suitable for farming purposes?

MR. R. W. McCASLAND: Part of it. If you will, I should like you to tell us some of your own experience concerning subsidence in Illinois, being a flat country, whether the advanced line of subsidence is in advance of the face or directly over it or behind it.

MR. J. W. PAUL: A record of some of the observations taken in Illinois will be found in some of the recent *Proceedings of the American Institute of Mining and Metallurgical Engineers.* The United States Bureau of Mines and the state of Illinois have been co-operating in taking observations for about six years in parts of the Illinois coal field in the northern or long-wall section of the state, and the room-and-pillar operation in the southern section. The subsidence is very manifest on the surface of these operations. The depth of the coal ranges from 300 to 600 feet. In the long-wall workings the subsidence on the surface follows some

little distance behind the face of the coal. It is appreciable to the eye. At one particular place the workings passed under a large district high-school and caused a number of cracks in the building as the subsidence started under it. But after the wave had passed, all those cracks closed and I think there is only one crack now that can be observed and that is in the foundation. It was a brick building with a concrete foundation and in some parts of the building on the second floor the cracks were as much as two inches wide. Now the subsidence has ceased, the building has come back into good condition, and apparently has not suffered any permanent damage.

On the contrary, the room-and-pillar method is destructive to the buildings on account of the irregularity of the subsidence and the unevenness of it; so, in Illinois, it has been found that the subsidence caused by long-wall mining in much less harmful to the surface and to buildings. It is my opinion that subsidence over room-and-pillar operations can be made more uniform by establishing longer break lines, and by the complete removal of the pillars of coal. The loss of pillar coal in many mines is due to the use of pillars that are too small.

Mr. E. C. Hulbert:* A few years ago I was asked to testify in a case brought in the United States court at Chicago by the Marquette Portland Cement Company, which was operating a limestone mine at Oglesby, Ill., asking an injunction against the Oglesby Coal Company which was operating a coal-mine, on the long-wall system, about 400 to 500 feet below the limestone mine, claiming that the subsidence of the strata above the coal was ruining their limestone mine and rendering it very dangerous to operate.

I made an examination of the limestone mine and found the floor of the mine had subsided in places as much as 18 inches and the walls were considerably cracked and broken, making the operation of the mine very unsafe.

The court granted the injunction, but the matter was adjusted later by the cement company buying out the coal company.

*Civil Engineer, Crescent-Portland Cement Co., Wampum, Pa.

Mr. W. A. Weldin, *Chairman*: I hesitate to raise the question of costs, yet, as the speaker pointed out, the object of the operation is to make money, and even though we have a superior method of mining, we cannot ignore the matter of cost. Mr. McCasland you need feel under no obligation to answer my question, but could you give us any idea as to whether in changing from room-and-pillar to long-wall, or in a new mine, it would necessarily entail any increase in the cost of mining?

Mr. R. W. McCasland: I would say in a general way that, starting with a lot of new and inexperienced men, it will cost more during the period in which you are training your men; but there can be no reason why the cost should not be lower by the long-wall method if there is an equitable rate for cutting and loading the coal. In our mine the cutting is just one-half the breast-machine rate and the cutters make a wage that compares very favorably with the cutters in other mines operating short-wall machines, to say nothing of breast machine.

To be entirely fair with the miners, I do not believe an inexperienced long-wall miner, even though he may be experienced otherwise, can go into the mine and immediately earn as much as he will otherwise. I think the figures I gave you concerning this mine will bear that out. It takes a considerable length of time for them to learn and to get used to the closer quarters; but it is also proved that they will load at least 12 tons as compared with six or eight in a room-and-pillar system. If you can get an equitable adjustment of your mining rates that is enough to pay for the extra cost, you save on your yardage and dead work. One thing about it, you pay as you go or you don't go, while in room-and-pillar work there are some things that you can put off. The extra expense of carrying it as you go along is mainly to keep the air course open, which I believe is lighter in long-wall that it would be in room-and-pillar work. Of course your varying roof and floor conditions affect the result so you cannot make absolute statements.

Our loading rate is 9/11 of the usual loading rate in that district and the figures per man show that that rate is too high. The hauling of the coal requires, as I said, practically the same number

of men. You have the same number of men at the haulage and the same number at the shaft and tipple and the increased number of day men is offset by the saving in yardage and dead work. In 13 places there will be 26 loaders. Each of these roads will have to be brushed every other cut. It requires the equivalent of one man to do that. Two work together, so it requires two men one-half shift to brush the road—two brushers, one-half day on each of those 13 roads; that is, 6½ days per machine cut. That is if the material is soft enough so that he can drill and load by hand. If it is hard, it will require a drilling crew for seven or eight brushers. I think that can be improved on by improved mechanical methods, but that is what is actually required. In addition to these 6½ days in following up your motor road and putting it in shape so that it will remain a permanent road you would have two men on what we call back dressing. The varying item in the cost is due to the nature of the material you have to brush.

Mr. W. A. Weldin, *Chairman*: There is one phase of the subject that has not been touched upon, and that is modified long-wall. You know there are attempts to get away from the building of pack walls, etc., by various schemes and a favorite way is to drive these roadways very much the way Mr. McCasland sketched in his general scheme for the conveyor, but in solid coal with a long face between these two headings, and with a conveyor across, the roof is caved as the face advances, keeping chain pillars and barrier pillars along the heading until the retreat. Has any one here had any experience along that line? It occurs to me there would probably be a difficulty right at the junction of the caving with the roadway. In some sketches we see the haulage way is outside the pillar right along the edge of the caved area. It is evidently an endeavor to include all the advantages of the long-wall system without actually going into long-wall.

Mr. G. B. Southard: We mined the first experimental face to a depth of about 200 feet and supported the haulage-way with cribs along one side. The other side of the haulage-way was a solid rib of coal. This was in the caving method and we found the

cribs were satisfactory for breaking the top along the back and at the same time maintaining the roof over the haulage-way along the front side.

MR. W. A. WELDIN, *Chairman*: You have a barrier on the other side of the heading?

MR. G. B. SOUTHARD: Yes, on the other side of the pillar. Where we are now working the faces were first stepped or offset about thirty feet, but we have reduced this step to about twenty feet in order to reduce the amount of cribbing necessary to maintain. We find that the cribs are more expensive to build and to remove than posts, and in order to eliminate some of this expense we are now beginning to use heavy timbers instead of the cribs. These cribs and heavy timbers are used to protect the main conveyor where it extends past the first face to the conveyor on the second face.

MR. W. A. WELDIN, *Chairman*: How are the various faces related to each other? Is there a haulage-way and then a face, then another haulage-way and another face?

MR. G. B. SOUTHARD: The haulage or main conveyor is laid in an entry which runs at right angles to the direction of the faces. The faces are each 100 feet long; one to the right and the other to the left of the main conveyor. This entry is driven through solid coal and the faces are worked retreating. All the coal is removed and the timbers are taken out to within 15 feet of the face and the roof allowed to break. Our first experimental face was 75 feet long and the operation there was entirely successful. The faces we are now working are 100 feet long, but this distance may be increased or diminished as subsequent results may determine. In other words, our present efforts are to determine what length of face is best suited to our conditions.

MR. W. A. WELDIN, *Chairman*: Your system might be described as the long-wall retreating method. You take a clean sweep of the territory and have your roadway driven in advance through the coal, and you are coming back.

Mr. G. B. Southard: I do not know what the right name is. It is hardly a true long-wall, but it could probably be classed as a modified long-wall. Of the examples described by Mr. McCasland our method most nearly approaches his conveyor method except that we use two face conveyors, discharging onto a central conveyor; whereas he used one face conveyor discharging onto an end conveyor. Furthermore, his method was advancing while ours is retreating.

Mr. W. A. Weldin, *Chairman*: I had in mind, when I referred to modified long-wall, an advancing system with protecting pillars left and chain pillars between headings. Mr. Paul are you familiar with any of these methods?

Mr. J. W. Paul: I know a case in this state where they have attempted to work a long-wall panel advancing. It is a mechanical success, at least. In some of the central western states, especially Oklahoma, where they have the pitch, they have successfully used the long-wall panel retreating; and in cases where there was sufficient to allow slides, that made it easy to handle the coal. In some other cases they used water to flush it down.

LOCAL EARTH MOVEMENTS IN WESTERN PENNSYLVANIA

By Leonard F. Bechtel*

I doubt if there is any other of the commonplace subjects with which the construction engineer has to deal which causes as much perplexity and anxiety as the treatment of slips. I call it commonplace because in sections having such topography as Western Pennsylvania there can be no disturbance of the earth surface without at least some hazard of producing slips, the extent of which will be determined by the magnitude of the work and the topography of the country.

Methods of treatment cause great perplexity and anxiety, because they cannot be reduced to rules and mathematical solution, but must depend on individual sagacity and experience. The difficulties are increased because the causes are very often concealed and not suspected until movement actually occurs. In general, the cause of most slips is a lack of free passage for water, and we would conclude that nearly all slips can be cured or prevented by adequate drainage, which seems very simple and logical and regarding which we may all agree, but any body of engineers might easily find itself divided on questions regarding the location and character of drains.

It would appear to be axiomatic that the subject admits of no general treatment, but that each slip is a problem of its own and must be treated after thorough investigation of its characteristics as to topography, soil, and sources of water. Slips, however, do admit of some classification as to their general characteristics, and in considering them we may separate them into two general classifications—natural, and artificial.

The first, or natural, I should define as those movements of earth from positions and locations as arranged by natural forces. Then, in addition to this, it seems to me, from such experience as I have had with slips, that natural slips can be again separated into what, for the sake of better terms, I have taken the liberty of calling superficial slips and fundamental slips.

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Superficial slips I should like to define as those movements of small bodies of earth along the surface of more stable underlying formations, usually accumulating other small bodies and finally forming an avalanche-like mass. These accumulate great momentum and often occur in short periods of time.

Fundamental slips are those portions of the earth's surface which move for lack of sufficient stability of foundation to support the moving body of earth. These are usually very slow in their movement and generally periodical.

Artificial slips can readily be understood to be those bodies of earth placed in given locations by artificial means and refusing to remain so placed.

As previously stated, it seems impossible to discuss this subject adequately in the abstract. Something may be accomplished, however, by citing such examples of slips, which have occurred in this vicinity and under my observation, as may illustrate each of the previously suggested classifications, taking into consideration the probable causes, the extent, and the means of control. I have selected slips occuring in various sections of Allegheny County and as each one is considered we shall attempt to determine its classification.

First, I should like to call attention to the slips occurring along the Glenfield road, going west along the Ohio River from Glenfield station to Sewickley. This hillside is inclined to slip down onto the road for nearly its entire length, and large quantities of earth are removed annually. There seems to be no movement of the road itself, but varying sized masses are deposited from above. A careful examination of this hillside indicated a series of substantial shale ledges arranged like steps to a flat or bench above. All of these rock ledges discharge considerable water at all times, especially during the spring season. The bench above is flat in some places and even swampy. Slipping from time to time has caused large cracks along the edge of the flat above and at various places along the slope, which easily prevent the flow of water from a large and rapidly discharging drainage area, thoroughly saturating the loose clayey overlying soil until it becomes an almost fluid mass for a considerable depth, and, like all fluids, attempts to find its level.

I should classify this as under the head of natural-superficial. Now to control such a slip as this would require very extensive treatment which on private properties might present difficulties and cause expenditures greater than would be warranted, but some of these slips involve a considerable hazard to life and I am confident fully justify a systematic and extensive treatment. It is my opinion that a system of diagonal lateral tile drains placed in deep trenches filled with stones or gravel and discharging into a larger drain placed in the natural water courses, and the confining of the waters on the bench above will effectually stop these slips.

Passing along this same bluff to the most recent slip which occured within the limits of the borough of Glenfield we find practially the same condition; a great mass of earth—the accumulation of loose material from an elevation of probably 200 feet above—becoming thoroughly saturated with water, moving down until the road passage is partly blockaded, carrying with it trees and steps of private dwellings and just missing the foundation of the dwelling. I want to call attention to this slip because it seems to me that the location of a water line for the supply of the dwelling has in a large measure influenced the slip. The dwelling is supplied with water from a spring near the brow of the hill by means of a half-inch, wrought-iron pipe carried diagonally down the face of the hill and into the house. Now, it seems significant to me that the center of slipping should have been just about where this pipe-line terminates. The outside surface of a pipe-line such as this forms a very convenient passage for water, and the ditch itself in which the line is carried would have a tendency to divert the water along the line of the pipe and concentrate it near the dwelling and at least hasten the slipping. There is no doubt in my mind but what the extent of the slip would have been considerably less had proper drainage passage been provided for the ditch in which the pipe is laid. The slip could undoubtedly have been prevented by a system of diagonal drains.

I would like to continue our journey across the Sewickley bridge, turning to the right to the Narrows Run road which is constructed on a ledge above the Pittsburgh & Lake Erie Rail-

road and close to an almost vertical bluff rising to a height of about 100 feet. This road is continually slipping away and settling in various places and is very difficult to maintain. Undoubtedly a retaining wall is advisable between the highway and the Pittsburgh & Lake Erie Railroad because in some places it is impossible to secure the natural slope of 1½ to 1. The slopes as they now stand are about 1 to 1, but I am convinced that an extensive drainage plan (by drainage I mean confining the surface waters and securing proper discharges for them, and in addition cutting off the ground water for a considerable depth below the surface) would almost entirely obviate this difficulty.

I should like next to call attention to a very extensive slip on the new state highway about one mile east of Carnot. This location is one where the road is cut around the brow of a hill, which slopes both above the road and below the road at about a 1 to 1 slope for a distance of probably 100 feet to a creek. In the construction of the highway it was necessary to secure some additional width of road by filling over the edge. This was accomplished by using the shale and clay material from the excavation in the vicinity. After the road had been entirely completed the rains came and the filled foundation of the road slipped out, carrying with it large trees and considerable heavy undergrowth and piling a great mass of earth at the creek below, undermining the highway for nearly half its width. The unfortunate part of this situation is that the nature of the ground makes it impossible, or rather impracticable, to fill far enough to secure a slope of 1½ to 1. The best that can be secured is the natural slope of the ground, which is about 1 to 1. The question of remedying such a slip is one which admits of considerable argument and just exactly what is best to do is a problem. It was deemed advisable, first, to determine the nature of the underlying strata and four well holes were drilled from an elevation about 30 feet below the road level. These holes were drilled to the solid rock, which was encountered at 85 feet. At a depth of 50 feet, soft red clay was encountered and below this a considerable amount of water. It was deemed advisable to place charges of dynamite in these holes and shoot up the underlying rock, breaking up the water

courses which had been formed and allowing the water to fall to a lower level, drying out the strata immediately underlying the necessary fill. This has been accomplished with some success and it is now the intention to replace the slipped material with slag. It is my opinion that, if this new material is properly placed, a sufficient foundation will have been obtained to carry the road-bed.

Throughout the whole of Western Pennsylvania the faces of all our hills show considerable evidence of slippage from time to time. Most of the cases which I have seen come under the same classification as the instances which have just been mentioned, and it is my opinion that by far the best plan of remedy and prevention is careful and extensive drainage systems. Retaining walls and piling are very often effective, but are very expensive and sometimes fail to effect the remedy desired. There are instances when, in my opinion, very simple and not expensive methods could be used to prevent slips which have caused great damage and great expense. I have in mind one which occurred this spring on our Elkhorn & Monongahela road, near Monongahela City. The road at this point is built along the side of a very steep hill, with the Pittsburgh & Lake Erie Railroad immediately below it. The road-bed is supported by means of a very light retaining wall, somewhat in the nature of a curtain wall. Ten-inch well casings were drilled into solid rock and filled with concrete, having been spaced four feet on centers, wrapped with reinforcing metal and encased in concrete, forming a retaining wall and parapet. At one point, where the precipice rises about 400 feet almost vertically to a township road above, the whole hill came down after it had been thoroughly saturated from the spring rains, blocking the highway, filling it to a height of 20 feet, breaking the wall above mentioned, bending the well casings at right angles and depositing a great mass of mud on the railroad tracks below. This is probably the most expensive slip which has come to my attention, and I believe it was caused entirely by the concentration of surface water, from the township road above, which was allowed to discharge at this point saturating the entire mass until finally it was unable to sustain its own weight.

In referring to the slip at Glenfield and the water line which crosses it, it seems to be of some significance to observe that at this point a six-inch oil or gas line passes vertically down this bluff and across the location of the slip. It seems to me very probable that this gas line helped to concentrate the water in this location. This factor of water lines concentrating water may seem to be insignificant, and in some measure it is, but my observation has been that water passages gradually increase; that is to say, the volume of water which any passage would be likely to discharge is very apt to be increased each succeeding year until finally so much has accumulated, and the fissures in the earth have been opened to such an extent, that the whole mass loses its stability. I am thoroughly convinced that a well constructed gutter which would gather the whole discharge from the township road above, and the proper conveying of this discharge down the full face of the bluff, would entirely have prevented two slips which occurred in this location and cost in the neighborhood of $10,000.

The theory that water accumulates from year to year, and finally causes slipping, is verified by the continual occurrence of slips in what have been considered well compacted road-beds, which have remained intact for a considerable period of years until suddenly the whole mass settles.

There are three methods for the prevention of slips.

The one previously mentioned is adequate drainage. There is no doubt in my mind that a well drained, perfectly dry embankment will retain itself at the correct slope; provided, of course, the foundation is sufficient to carry it.

Another method is furnishing a retainer. This is by far the most expensive and very often the least satisfactory method.

The third method is in the preparation of the foundation upon which the embankment is to be placed. It seems to me to be very often considered, in placing considerable quantities of earth in new locations, that the embankment is merely a dump; and thus proper precaution and care in placing are very often lacking. In placing filling, the whole mass should be considered as a structure and it is surely the part of wisdom to investigate the

foundations upon which such a structure is to be placed before the operation is carried out.

Along this line I might mention a project which is now in course of preparation which involves filling across a ravine, involving about 100,000 cubic yards of filled material. Before this material is placed, it is the intention to sink several shafts in convenient locations for the purpose of investigating and determining the exact character of substrata and the best means to be employed for their preparation. In this instance it is expected that the preparation will consist of breaking up the subsoil all the way to solid rock, diverting the passage of the earth water, and disturbing any plane of slippage which might exist, and in addition to this, providing ample drainage to intercept any streams which might tend to saturate the mass in the work.

DISCUSSION

Dr. C. S. Palmer:* I would like to ask whether in the case of artificial slides, the ground may move for a year or two and finally come to rest. I live on Dakota Street, Schenley Heights, where we have had a very bad slide; and it has been growing worse and worse until about a year ago. In front of my house a good concrete walk has sunk down out of sight. They have built up a platform 10 or 15 feet high above the ground; and it is apparently getting stable. This year a great deal of vegetation has grown, including a great many young trees, and that may have helped. Is there any probability that the slide will ever start again?

Mr. Leonard F. Bechtel: It is absolutely impossible, in my opinion, to prophesy in regard to slides. The unexpected always happens. In places where we very often feel absolutely certain that the earth would retain itself it comes down. I do not want to discourage your expectation, and I would say that there is a possibility of it finally compacting itself and finding some means of supporting itself, but an opinion depends altogether upon the character of the topography, the nature of the vegetation—whether it has tap-roots or not, for tap-roots sink into the earth and act as a sort of pile and absorb the water from greater depths, and it may possibly find its level and stop slipping. My experience, however, is that such places will stop for a few years and finally move again.

Mr. R. P. Forsberg:† I thought as I listened to the reading of the very interesting and instructive paper that Mr. Bechtel has given us that I have one objection or criticism to offer. He should have presented the paper to our Society just 10 years sooner. Just 10 years ago I was employed by one of our north boroughs to make an investigation and submit a report relative

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to a rather serious slide which had occurred within its limits. If I had had before me at that time the information given us this evening it would have been of material assistance to me in investigating and solving my problem.

I am in agreement with the author in his statement that the proper solution of the cause of the average slide, and a remedy for its correction, is not a question of mathematical niceties. Each problem must be studied and solved independently and the training and skill and experience of the engineer making the investigation are all-important factors. Mr. Bechtel elects, in presenting his subject, to use example rather than precept and I shall follow his method in presenting to you very briefly a description of the slide to which I have referred.

I was sent for in the spring of 1912 by the borough council of Bellevue and informed that a slide in that borough had been in progress for a number of years, resulting in property damage and causing a spirit of uneasiness among the residents in its vicinity. I was requested to make an investigation relative to the cause of the slide and suggest a remedy for arresting its further progress.

The first step in my investigation, of course, was to make a survey of the affected zone and have cross-sections taken. While that was being done I made a search through the engineering literature readily at hand, hoping that some brother had at sometime been confronted with a similar problem and left a record. I was disappointed in not finding the information I sought. I had hoped that my file of *Engineering News* would have given me something of practical value, for I am the fortunate possessor of a complete file of that publication from its first appearance in April, 1874, to date. Please do not infer that I was practising engineering in 1874, but my father was a civil engineer and I inherited his library and have kept intact the file of the, now, *Engineering News-Record*. The editor of that publication secured a copy of my report on the Bellevue slide and it was published in full in its issue of January 1, 1914.

The completion of my survey showed that the slide was located between Rodgers (now Balph) Avenue and Summit Avenue, that it was about 400 feet long and 200 feet wide. The

vertical distance from the top to the bottom was about 65 feet. The street paving in Rodgers Avenue had been raised in many places about two feet above the general elevation; some of the sidewalk concrete slabs had been thrown out into the driveway; the retaining walls in front of several properties had been overturned; and several dwellings had been renderd wholly unfit for occupancy.

The residents of that community were naturally apprehensive, some fearing that their property would ultimately find its place in the bottom of the adjacent ravine. A careful examination showed that there were no breaks in the surface of the slide between its toe in Rodgers Avenue and its top near Summit Avenue. At its top and extending throughout its length was a crevice from one to eight feet wide of varying depth and quite similar in its appearance to some of the views shown this evening. I was told that this crevice usually made its appearance in the spring. The residents would at times have it filled only to see it open again the next spring.

I next proceeded to investigate the strata underlying the slide and sunk two test holes. The first one was located in Rodgers Avenue at the foot of the slide. We went through about five feet of disintegrated or soft shale rock where a six-inch vein of fire-clay, thoroughly saturated, was encountered. We then sent a steel drill down six feet below the vein of clay through good shale rock. The second test hole was driven about 120 feet from the first at right angles to Rodgers Avenue in the direction of Summit Avenue, and its elevation was about 17 feet above the first. After drilling through 21 feet of soft shale rock we encountered a vein of fire-clay 21 inches in thickness through which water was flowing rather freely. I concluded that the water came from one of, or a combination of, three sources—improper surface drainage, a leaking water main in Summit Avenue, or natural water veins. From further investigations, which we do not have time this evening to relate, I determined that the water came from natural water veins.

After a comprehensive study of the data I had obtained, which I set forth in some detail in my report, I recommended to the borough council that we should proceed first to excavate at

the foot of the slope in the rear of the dwellings, about 120 feet from Rodgers Avenue and parallel with it, shafts six by six feet spaced 30 feet center to center, these shafts to continue throughout the length of the slide. They would extend about two feet below the bed of fire-clay which would make them about 25 feet deep. Between these shafts and at an elevation of the bottom of them, a tunnel three feet wide by four feet high would be driven. In the bottom of this tunnel eight-inch terra-cotta drain pipe would be laid with open joints. The trench or tunnel would then be backfilled with gravel. The shafts from their bottom to a point four feet above the fire-clay should be backfilled with concrete reinforced with a few vertical rods, which would offer an additional resistance to the movement of the slide. The terra-cotta drain pipe would be connected to the sewer in Rodgers Avenue.

I further suggested that, when the foundations of the residences in the slide zone were rebuilt, they should be carried down two or three feet below the vein of fire-clay. The foundations would be built of concrete and with the weight of the houses on top would offer an enormous resistance to horizontal movement. The effect of the slide movement could be further retarded by starting at the break in the ground at the top of the slide near Summit Avenue and grading off the side-hill on a slope of 1½ to 1, until it reached the elevation of the ground in the rear of the houses on Rodgers Avenue. This would remove a weight of approximately 19,000 tons and accordingly reduce the propelling force.

Upon the submission of my report a discussion arose in the council as to who would bear the expense of the undertaking. Months passed and no definite action was taken. The borough engineer suggested that the two test holes that had been excavated be refilled. This was done and they were refilled in the manner I had suggested for the main drainage tunnel, the two test holes being connected with an eight-inch terra-cotta pipe with open joints, backfilled with gravel, which pipe was in turn connected with the sewer line in Rodgers Avenue. Water at once began to flow into the sewer line from the test holes. The next spring the crevice at the top of the slide for the first time in years failed to make its appearance. The spring and summer passed

and there were no indications of any movement whatever in the slide. After a year or more had elapsed and the menace of the slide was being forgotten, the residents of the affected zone took heart and rebuilt their properties, the borough repaired the street and apparently the Rodgers Avenue slide was a thing of the past.

I rather expected that I would be called upon this evening to relate some incidents in connection with the Bellevue slide and I accordingly called up the engineer of that borough last evening and made inquiry of him relative to its status, and he informed me that the slide had been at rest since the fall of 1912, and the residents of that community had dismissed it for all time from their minds. The sinking, therefore, of two test holes, later connected with a drain pipe and backfilled with gravel, effectively arrested the movement of a slide that at the outset of my investigation appeared to be a rather serious and expensive undertaking.

I could easily recite from my railroad experience a description of other slides where movements have been corrected by various methods, but I will trespass on your patience only by briefly stating one.

In the construction of the Brownsville Branch of the Pennsylvania & Lake Erie Railroad between Fayette City and Brownsville, the major part of the grading was side-hill work. We, of course, had local settlements and slides that are always incident to the construction of a road-bed; but none of any consequence. A few years later, however, when we double tracked the road-bed by filling out on the side-hill towards the river with slag, we encountered quite a little difficulty at one point in retaining it. Our trouble was finally successfully overcome by drilling a line of two-inch holes spaced 10 feet apart near the edge of the river, for a length of about 80 feet. These holes were drilled five feet into the rock, charged with dynamite, and electrically exploded. An artificial toe was thus thrown up of sufficient height to arrest and prevent any further movement of that slide.

I would say as a result of about 25 years' experience in railroad construction and maintenance that I would never resort to the use of retaining-walls, piles or any other artificial barrier to

arrest the movement of a slide if it were at all possible to provide for the free drainage of the water that caused it.

MR. V. R. COVELL:* What is the inclination of that vein of fire-clay?

MR. R. P. FORSBERG: As we put down only two test holes, we did not have sufficient data to determine its inclination accurately. I would say from the evidence we had that it sloped towards Rodgers Avenue at a rate of about two feet in 100 feet.

MR. H. R. THAYER:† In some respects I differ from the preceding speaker and in others I agree with him. In the first place, mention was made of the literature. I know of only two articles in scientific literature that deal with it. At one time it was a matter of importance to me and I looked it up pretty thoroughly. One is mentioned above; the other is a paper by D. D. Clarke, entitled "A Phenomenal Land Slide,"‡ and dealing with a case in Oregon. It is interesting to note that the writer of this paper handled the problem in almost the same way as Mr. Forsberg did. It occurred about the same time.

MR. ROBERT A. CUMMINGS:§ It is a great object lesson that Mr. Bechtel has presented to us. The problem of land slides, etc., is worthy of our earnest study and investigation. This can best be accomplished by a review of the physics of soils in a manner similar to that undertaken by the American Society of Civil Engineers.

I recall that several years ago the subject was brought before this Society and a committee was appointed. The committee seems to have vanished into thin air for nothing has been heard from them. I know of no problem in the whole field of civil engineering that is comparable in importance with the urgency and need of investigating the influence of soils on engineering structures. Let us, therefore, renew our efforts in this direc-

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†Markhart-Thayer Engineering Co., Pittsburgh.
‡Trans. A. S. C. E., v. 53, p. 322.
§Consulting Civil Engineer, Pittsburgh.

tion with greater determination to achieve something of technical value.

For this reason, Mr. Chairman, I move you that a committee of this Society be appointed to report upon soils and their physical relation to engineering undertakings, the number and the appointment of this committee to be left to the Chairman.

MAJOR J. F. BELL:* I did not expect to talk on this subject and I will talk about it only so far as to refer to some things I have seen. If any of you should have work to do in another part of the United States, be very careful. The means you adopt here may not apply there. Take the lower Mississippi Valley. We do not refer to earth movements as slips or slides there. They are called caving, wave wash, sloughing, and sinking, and there are general earth movements besides. You meet those movements in different ways.

The wave wash washes away the levees. You stop that by ordinary superficial protection by using plank concrete, Bermuda grass, willows, etc.

Caving is an entirely different thing. The water may be 100 to 150 feet deep and the bank be falling in at a rate of 200 feet a year. You meet that by taking the top off the bank and securing an easy slope. The most inportant thing is to remove the weight. The slope is then protected by mattresses.

A slough is the sliding away of the back of the levee. Our method is that followed by the French, as Mr. Cummings described it. The levee may be 30 feet high. Cut channels down the back and lead small inclined ditches into them. Do not make the mistake of putting earth on the back of the levee. If you hold the water in, the levee is sure to go.

Another type is "sinking." You have a levee that is standing all right. You try to build it a little higher and it goes down and the earth rises nearby. Often the only thing to do is to keep on piling earth on top of it until you get a counterbalance. That will permit an increased height. In cases like that you probably have quicksand underneath and there is no use trying to drain it.

Another illustration is found in the lower end of New

*U. S. Engineer Office, Pittsburgh.

Orleans. For about a mile or a mile and a half the bank of the river is moving out. It has moved several feet in recent years. The whole body of the land is moving out. There is quicksand underneath and the problem is still to be solved.

Mr. H. R. Thayer: Western Pennsylvania was formerly a bed of shale and silt lying at the edge of a vast inland sea occupying what is now the basin of the Mississippi. Then some convulsion of nature elevated it, and the drainage systems began to cut out channels. The resulting topography in the vicinity of Pittsburgh has been a series of ridges and valleys. The surface of the shale has disintegrated into clay, and every engineer in the district realizes the problem thereby created. Every cut in these slippery slopes brings with it its risk. They speak about "putting money in a hole" but those who have to contend with a slide do not even get this satisfaction, for the ooze soon fills up every last semblance of any excavation.

I do not know of any better example, however, of the useful application of the truths of science to every-day affairs.

We may classify earth movements as of five different types:

The first occurs where the earth is deposited or cut into at a slope exceeding the angle of repose, usually assumed for earth at about 34 degrees. The usual and proper remedy is to flatten the slope or to build a retaining-wall if the former course is impracticable

The second case is where a heavy load is placed upon the earth. This is really a special case of the first variety and has the same remedies.

The third case is that caused by the disintegration of the material. It gives trouble where too high an angle of repose has been assumed. This is an error likely to occur when excavating in friable rock.

The fourth case, fortunately rare in this district, is caused by earthquakes. There is no remedy; at least, none at present. One has to take what is sent him.

The fifth case, common in this vicinity, is what is called a "slide." In a hillside, apparently solid, an irregular mass breaks loose. The top cracks and heaves in an irregular manner, while

a clayey mass pushes out as a toe at the bottom. The motion may be very slow, say a few inches per year to a few inches per day. The force developed is very large and construction to hold it must be correspondingly massive.

So far as the writer knows, slides occur only in a clay coil. Keep clay perfectly dry and it is a most dependable material. Under these circumstances it will remain vertical for a long time if not indefinitely; but water changes its character entirely, rendering it a most treacherous material. Its angle of repose becomes very low, possibly something like 10 degrees. As we should expect, the angle at which the clay will stand depends largely upon the moisture present therein; and if anything happens to increase its moisture content its stability is decreased and if this goes far enough movement begins and we have a slide. So far as the writer knows, water is the only cause of slides. If ground which has been stable for a long time starts to move, it will be because the slope has been changed or unusual amounts of water have been introduced.

There are four methods of treating a slide:

The first is to restrain it by means of piles or a retaining wall. Great strength is often needed to make this effective and these methods are always expensive. The next idea is to "dig it out." This is archaic, expensive, and generally unsatisfactory. There are cases, however, where it is the only thing to be done, although often involving very large amounts of material.

The third method is to drain the affected area, thereby removing the water, which is always the cause of the trouble. This is likely to be expensive but has proven quite satisfactory.

The last method is one of prevention. It is usually available and will be in every way the most satisfactory. The first step is a careful and thorough investigation. There should be a topographical survey with borings, also a history of the slide with rainfall records and progress chart. The amount of water flowing from the foot of the slide and its variation and nature should be carefully observed. The water may be from springs, from the surface, sewage, or water-supply. From the above data it should be easy to determine the source.

The next step—locating the definite place from which the

trouble comes—will not give engineers very much trouble as these methods are too well known to need elaboration here. If it be a leaky waterpipe it is resoldered or better still moved to a more favorable location. Sewer-pipe we may likewise mend or move, while surface drainage may be ditched off the slope. The treatment of spring water will give the most trouble, but, since this has always been present, the chances are that it is not the cause, unless someone has been careless enough to fill directly over a spring.

To prevent a slide:

> If possible, avoid digging into a clay slope carrying water in greater or less quantities. If it must be done, drain thoroughly and keep out all the water you can. Locate water and sewer-pipes as far away as you can. Turf the slopes.
>
> If water can be excluded, and you can be sure that external water will always be kept out, a slope of 34 degrees (1½ to 1) can be used with confidence.

Mr. Leonard F. Bechtel: It does not seem to me that there is any very great difficulty. We seem pretty well of one mind. It is altogether a question of drainage and a consideration of the quality and character of the soil that makes up the fill. In this locality particularly you must give attention to soils which absorb and retain moisture. There are some soils which cannot be drained. They simply hold moisture until it evaporates. These are soils from which the moisture must be kept.

I may have been misunderstood in the matter of the lifting or raising of the bottom of the land. I know that does occur. It is a very frequent occurrence. I meant to convey the idea that in the case of this particular slide it did not seem to have occurred; but where the low land can not be supported or there is no balance there must certainly be a movement somewhere.

CONCRETE PIPE; PLAIN AND REINFORCED

By Joseph S. Lambie*

The use of concrete pipe, or "cement pipe" as it is more frequently called, dates back to the year 1860 in this country, and probably ten years earlier in Europe, where it was introduced at approximately the same time in France and southern Germany. Brooklyn was one of the first American cities to adopt cement pipe for sewer construction. Starting in 1861, Brooklyn to-day has over 400 miles of concrete pipe sewers.

The first use of reinforced concrete is attributed to a Frenchman, Monier, who in 1867 conceived the idea of introducing wire mesh into ornamental concrete structures in order to strengthen them. No scientific efforts at placing the reinforcement or determining the proper amount were made until 1879, when a German, named Wayss, having seen Monier's exhibit at the Antwerp Exposition, bought the German patent rights and proceeded to make a thorough investigation of the possibilities of the combination.

The first designs for reinforced pipe are attributed to Bordenare in 1887, but very little actual construction was undertaken until five years later. From 1892 until 1895 was a period of decided activity in reinforced concrete pipe. Monier, Coignet, Bonna, and Hennebique, introduced various designs of pipe, of which the Bonna system seems to have been the most popular. Over 100 miles of this type of pipe had been installed in and around Paris before the year 1900. These pipes were in sizes varying from 12 inches to 6.5 feet in diameter, and in some cases were used under pressure heads up to 130 feet. For pipe under pressure a thin sheet-steel core was embedded in the concrete shell to prevent leakage, structural strength being obtained from spiral reinforcing and the concrete. A pressure line of this type was installed at Swansea, Wales, in 1905, and is still in use. This pipe was 20 inches in diameter; shell 2½ inches thick, containing a 20-gage,

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butt-welded, sheet-steel core. This pipe was tested under a 450-foot head without leak.

At present, concrete pipe is used almost exclusively for sewers in some of the European centers of population. Throughout the eastern United States and Canada, reinforced pipe is used extensively in the large sizes for trunk sewers. Throughout the West, and especially on the Pacific coast, the smaller sizes of plain pipe are used for branch sewers and house connections, being equally adaptable with, and cheaper than, vitrified clay pipe for this purpose. Until recently, the plain pipe used in the East was all hand tamped and its use was largely restricted for economic reasons and on account of its uncertain quality. The perfecting of methods for manufacture of machine-made pipe, and the remarkable improvement and reliability of the resultant product, have changed conditions to such an extent that plain cement pipe is now being extensively introduced into sewerage systems throughout the central and eastern states. Large reinforced pipe is used extensively in the West on irrigation projects under heads up to 150 feet.

One of the principal uses of small-size cement pipe is for farm drainage. Hand-made pipe was first used for this purpose in Illinois in 1872. The first machine-made cement drain tile was manufactured in Iowa in 1905. By 1911, there were 418 plants producing over 110,000,000 feet of tile annually, and this figure is now being doubled about every five years. The ease and simplicity with which this product can be manufactured has naturally led to the springing up of a considerable number of irresponsible manufacturers with the result that some inferior pipe has been placed upon the market and a number of failures recorded. Similar results were noticed a decade or so ago in the hollow-block industry and for several years threatened its demise. This condition can be overcome only by strict specification regulations and tests, and organization and education of those interested. Besides sewers, drains, water-supply and irrigation systems, concrete pipe, both plain and reinforced, is extensively used for culverts under railroads and improved highways, being an ideal material for this purpose. Many special and minor uses for the large-size pipe might be mentioned, such as mine entries, cattle passes, septic tanks, and silos.

The design of pipe is something that has been left too largely to the manufacturer and accepted on faith by the engineer and consumer. Someone has said that "A doctor buries his mistakes while an engineer makes monuments of his." A pipe-line is one of the exceptions. An engineer buries his pipe-lines and with them, I believe, buries more mistakes than are made in any other type of engineering structure. An occasional autopsy is likely to produce a coroner's verdict that failure was due to general debility, and exonerate the engineer from what was at least an equally probable cause—his error in diagnosis.

The fact that a pipe appears to be a very simple structure is possibly the reason that its proper design has been so generally overlooked by the engineering profession. I refer particularly to the load factor. Careful calculations are, as a rule, made for the carrying capacity, and if the pipe is to be subjected to internal pressure, the resultant tensile stresses are easily evaluated. Consideration of the effects of external loads is, however, too frequently slighted. In considering these, we are brought face to face with the difficult and but vaguely understood principles of earth pressures, very much complicated by the fact that they act from all sides of the structure under consideration. The action of earth pressure in a trench is materially different from that in a fill, and in many instances live loads are transferred from the ground surface above. These will be considered in detail in the order named.

The frequency with which sewer and drain pipe, on excavation, was found to be cracked led, in 1911, to the institution of a thorough series of tests at the experiment station connected with Iowa State College to determine, if possible, the intensity and distribution of earth pressures upon pipe in trenches of various widths and depths and with various filling materials. These tests were very comprehensive, covering trenches up to four feet two inches in width and 24 feet in depth and are reported in complete detail in their Bulletin 31. The conclusions there reached may be briefly summarized as follows:

The backfill in the trench, regardless of the method of placing, is not as compact as the adjacent soil and has a continued tendency to settle around and over the pipe. Under this condition, and on account of the rigidity of the pipe itself, the fill at the sides of the pipe exerts but little supporting capacity, but consid-

erable frictional resistance is developed between the rigid side walls of the trench and the fill placed therein. This acts as a partial support for the fill, and reduces the vertical pressure on the pipe. The total relative amount of this frictional support is dependent on several factors. It increases with the height of fill and decreases with the width of trench and degree of saturation of the filling material.

For ordinary conditions, and for trenches which are from five to six times as deep as they are wide, the frictional force is capable of supporting about one half of the total backfill, the balance being carried as a load on the pipe. This load is not equally distributed over the diameter of the pipe, but tends to concentrate towards the center, with the friction supporting that portion of the fill adjacent to the trench walls. As a result, the bending moment is greater than would be caused by a more uniform distribution. As already mentioned, the pipe is offered but little lateral support on account of the compressibility of the fill between its sides and the trench walls. The maximum loads will occur in trenches that are from 10 to 12 times as deep as they are wide; additional depth has little or no effect on the load borne by the pipe.

A pipe placed in a fill is under radically different conditions from one in a trench. If the pipe projects above the natural ground level, the greater heights of fill adjacent to the pipe will cause more settling than occurs in the fill over the pipe, thereby producing a dragging-down action in the prism of earth over the pipe, and increasing the load that the pipe must support. There is also a decided lateral thrust, which is comparable to the thrust which a fill exerts against a retaining wall. If the pipe is partly or entirely embedded in the solid ground beneath the fill, or if the fill is thoroughly compacted at the sides of the pipe and up to the level of its crown, the dragging-down action and the vertical load may be greatly reduced. The advantage thus gained is obviated to a large extent, however, by the corresponding decrease that would occur in the lateral pressure. Since vertical and lateral pressures cause opposite bending moments in the shell of the pipe, it is evident that their numerical difference produces the resultant moment. This numerical difference will hereafter be referred to as the "effective load." This problem is far more complicated than that

of a pipe in a trench, and is to-day attracting the attention of committees in several of the national societies. Foremost among these is the Joint Committee on Concrete Culvert Pipe, composed of two representatives each from the American Association of State Highway Officials, the American Concrete Pipe Association, the American Concrete Institute, the American Railway Engineering Association, the American Society of Civil Engineers, the American Society for Testing Materials, and the United States Department of Public Roads. Dean Marston of Iowa State College is Chairman of this Committee, which was organized in 1919 to draw up standard specifications for culvert pipe. Although this Committee is exceptionally active it has not as yet progressed beyond the consideration of the question of loads and the compilation of data thereon.

Dean Marston has offered all the facilities of the Iowa experiment station for the study of this question, having been previously interested through the studies he had made on trench conditions. Three years ago, he began an extensive series of tests under fills of varying heights and of various materials. Experiments were first conducted upon a culvert 40 inches in diameter and 20 feet long under fills of sandy loam top-soil up to 20 feet in height. This fill was maintained under observation for eight months and then gradually removed, observations being made regularly during this process, also.

With the experience gained in these tests, which lasted over a period of two years, a new series was started using sand and gravel for the fill and making observations for every foot of height up to 16 feet, which was as far as the experiment had progressed at the last report.

Results so far obtained are not sufficient to justify any definite conclusions, but it would appear that the dragging action above mentioned will increase the vertical loads on the pipe from 50 per cent. to 100 per cent. for the fills cited and for a pipe projecting almost entirely above solid ground. Little or no increase in vertical load over that produced by the prism of earth directly over the pipe was noted when the pipe was completely embedded in solid ground. Unfortunately, no effort was made to determine the intensity of lateral pressure caused by the fill. The tests are to be continued, however, and this factor will be given due con-

sideration. Until more definite information is available, it would seem safe to assume this at from one fourth to one third of the vertical pressure per square foot as is customary in retaining-wall practice. This would mean that the effective load on a pipe in a fill is from 1.2 to 1.5 times the weight of the superimposed prism of earth, or approximately twice the load that would occur on a pipe in a trench of equal depth. Under very deep fills (30 feet or more) it is probable that this ratio decreases considerably, due to the compacting of the fill at the sides of the pipe and the resultant lessening of the dragging action. This force in a fill is a shearing action rather than friction, and increases the intensity of loading towards the sides of the pipe rather than the center. Fig. 1 shows

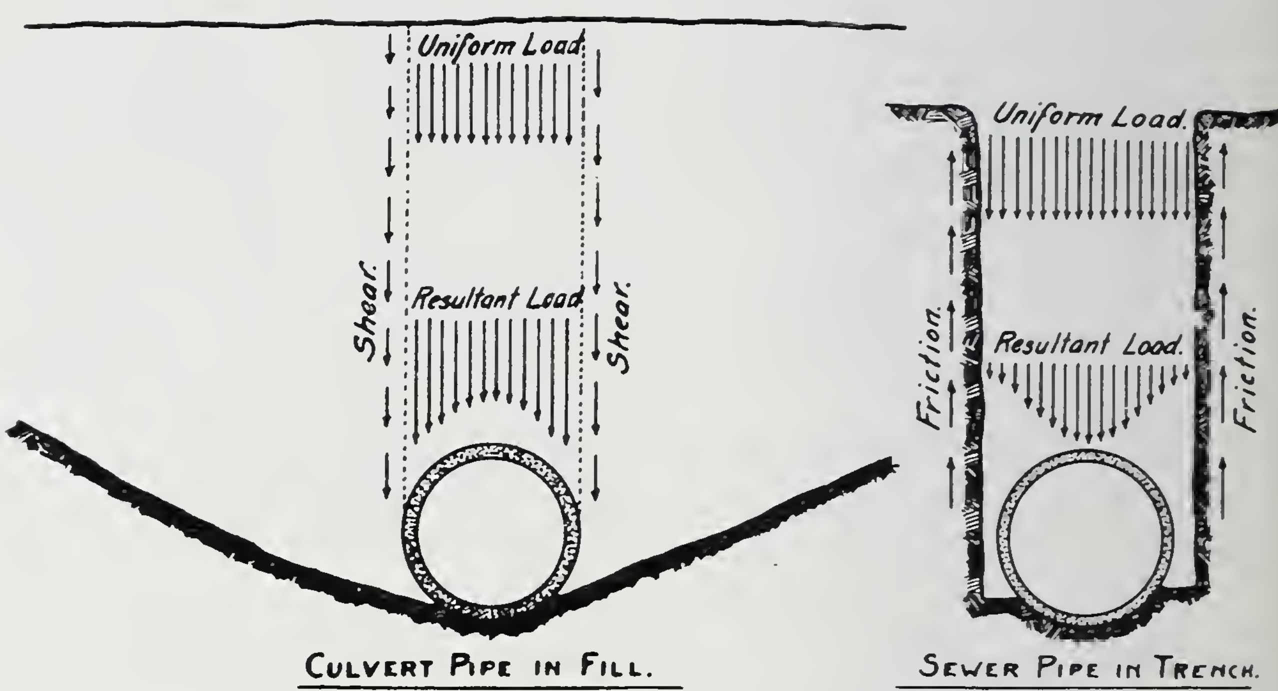


Fig. 1. Distribution of Vertical Loads.

the probable distribution of the vertical loads for both trench and fill conditions.

The effect of live loads, such as may be caused by highway or railroad traffic upon a culvert under the road-bed, is dependent largely upon the amount of cover, and, if this be small, may be increased by impact. No heavy concentration of load will occur if the pipe has cover equal to its diameter, and, for greater covers, the percentage of live load carried by the pipe decreases rapidly. Covers less than the diameter should be avoided if possible, and, if not, careful analysis should be made to see that the structure will

resist the impact of moving traffic. Fig. 2 shows graphically live load and impact allowances for concrete culverts

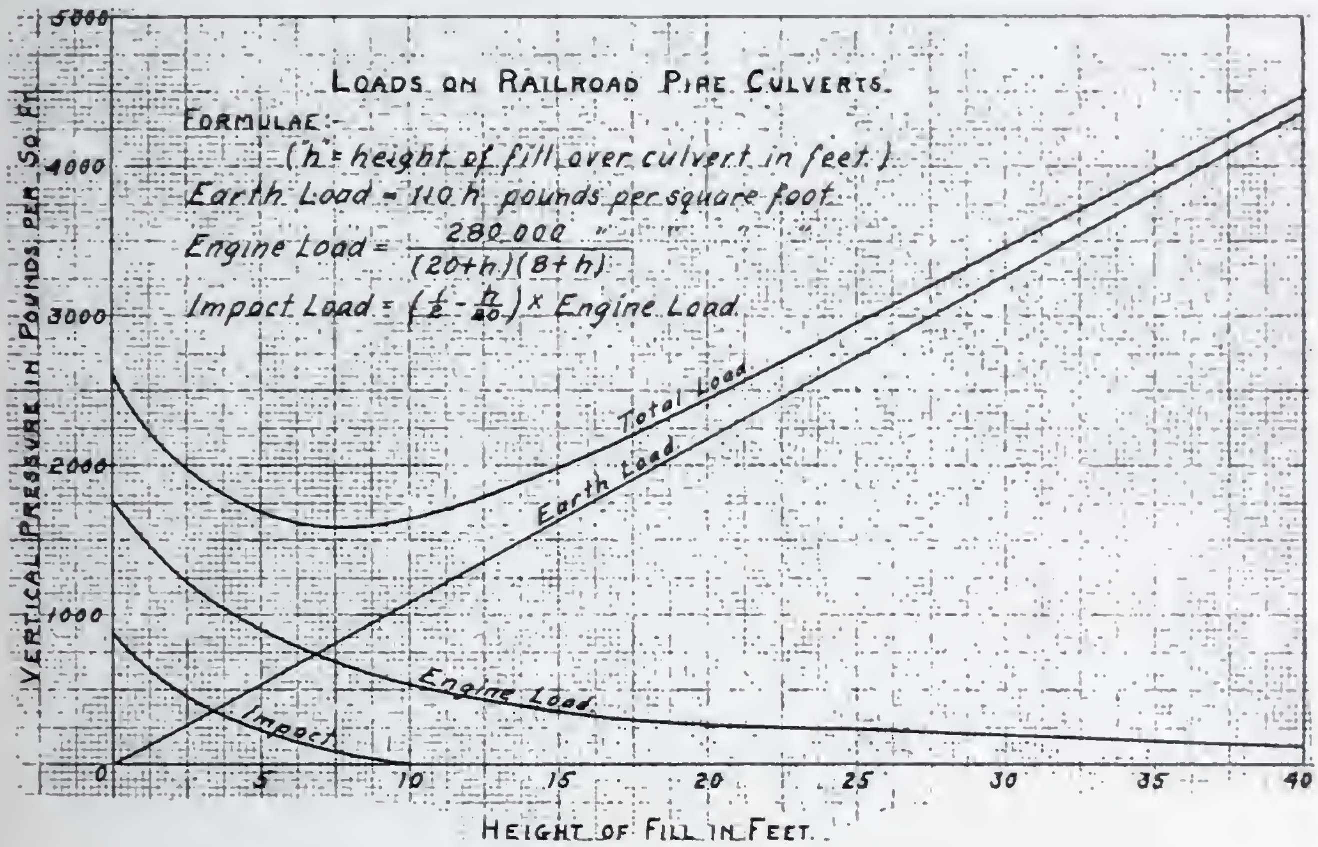


Fig. 2. Live Load and Impact Allowance.

under railroad tracks as presented for consideration by the American Railway Engineering Association. The live load is based on four 70,000 pound axle loads on five-foot centers, the soil pressure radiating outward and downward from base of tie on lines having a slope of 1:2. The maximum impact is estimated at 50 per cent. of the total live load, decreasing five per cent. for each foot of fill until it is eliminated at a depth of 10 feet. An allowance should be made for lateral pressure in estimating the resultant effective load under deep fills. Results obtained at Iowa State College by passing a loaded truck over a culvert covered by various depths of fill check closely with the preceding curve.

Having determined as nearly as possible to what load a pipe will be subjected, the design will be based on the bending moment that these loads will produce and a suitable factor of safety. Rational formulæ, based on the elastic theory, for bending moment of various types of loading on thin homogeneous elastic rings have been developed and are as shown in Fig. 3.

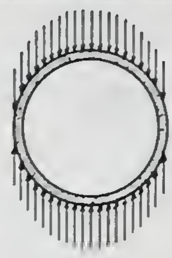
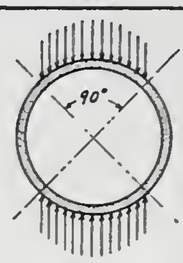
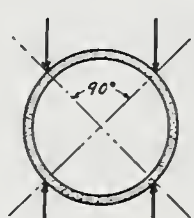
Method of Loading.	"W" = total load. "d" = mean diameter.	
	Crown.	Haunch.
	0.0625 Wd.	0.0625 Wd.
	0.0845 Wd.	0.0770 Wd.
	0.1592 Wd.	0.0908 Wd.
	0.0241 Wd.	0.0491 Wd.

Fig. 3. Load Moments for Elastic Rings.

Lateral pressure will produce a bending moment in the opposite direction, the resultant moment being the algebraic sum of two, or it may be calculated directly by using the effective load for "*W*."

The theory by which the above formulæ were derived was first explained by Filkins and Fort at Cornell University. It was applied extensively by Prof. A. N. Talbot in his tests on pipe made at the University of Illinois in 1907, with the result that the above are frequently referred to as the "Talbot Formulæ."

It is possible that plain concrete, and quite probable that reinforced concrete, when the character of the material and the relation of shell thickness to diameter are taken into consideration, will not accurately respond to the above formulæ. Comparison of results with straight beams indicates a marked difference in the

modulus of rupture, which would indicate that the actual moments in pipe are considerably less than the above values. As their principal use is for comparative purposes and test analysis, this is not of vital importance, and the formulæ may be considered satisfactory and perfectly safe until something better is developed. An exception occurs in reinforced pipe subjected to concentrated loads of sufficient intensity to crack the concrete and transfer the tensile stress to the steel. Under this condition, the structure is no longer continuously homogeneous, but becomes multiple hinged at the points of cracking, with the probable result that the moments at crown and haunch equalize at a mean between the values above given. This has been convincingly demonstrated in a series of tests made on large-size reinforced pipe at the United States Bureau of Standards laboratory in Pittsburgh.

In considering a suitable factor of safety for design, we must again give cognizance to the exceptional conditions under which pipe is ordinarily placed. Generally speaking, a factor of safety is necessary for three reasons:

1. To guard against inferior material or workmanship.
2. To guard against possible future overload.
3. To guard against deterioration.

Usually it is the last two elements that are most important in determining the size of the safety factor. With adequate inspection and tests, the material and workmanship can be controlled so that a product of great uniformity is obtained.

Let us consider concrete pipe from the standpoint of possible overload and deterioration. The greatest load on a pipe in service generally occurs shortly after the completion of the fill and probably during a period of heavy rains. As time passes, the fill solidifies and the load on the pipe gradually decreases. The Iowa tests show that the maximum load from a 20-foot fill occurred one month after its completion and a few days after a rainfall of 2.6 inches. This load was 192 per cent. of the weight of the directly superimposed earth. Six months later, it had decreased 2000 pounds per foot to only 5/6 of its former value. Heavy rains increase the weight of trench fill and reduce the frictional resistance at the sides. I know of one case where a trench was sheeted and the sheeting left in place after backfilling, with the result that a particularly heavy rain caused failure of the pipe. Analysis

showed that the pipe was evidently subjected to the full weight of the backfill. Additional fills on top of a thoroughly solidified old fill will produce but slight increments of loading.

There is another difference between pipe-lines and other structures: Most failures tend to accentuate themselves; but, in the case of a pipe subjected to external earth pressures, the greater the failure of the pipe, indicated by deflection, the greater the resistance of the surrounding soil to its extension.

As indicative of this, attention is called to Fig. 4. The three

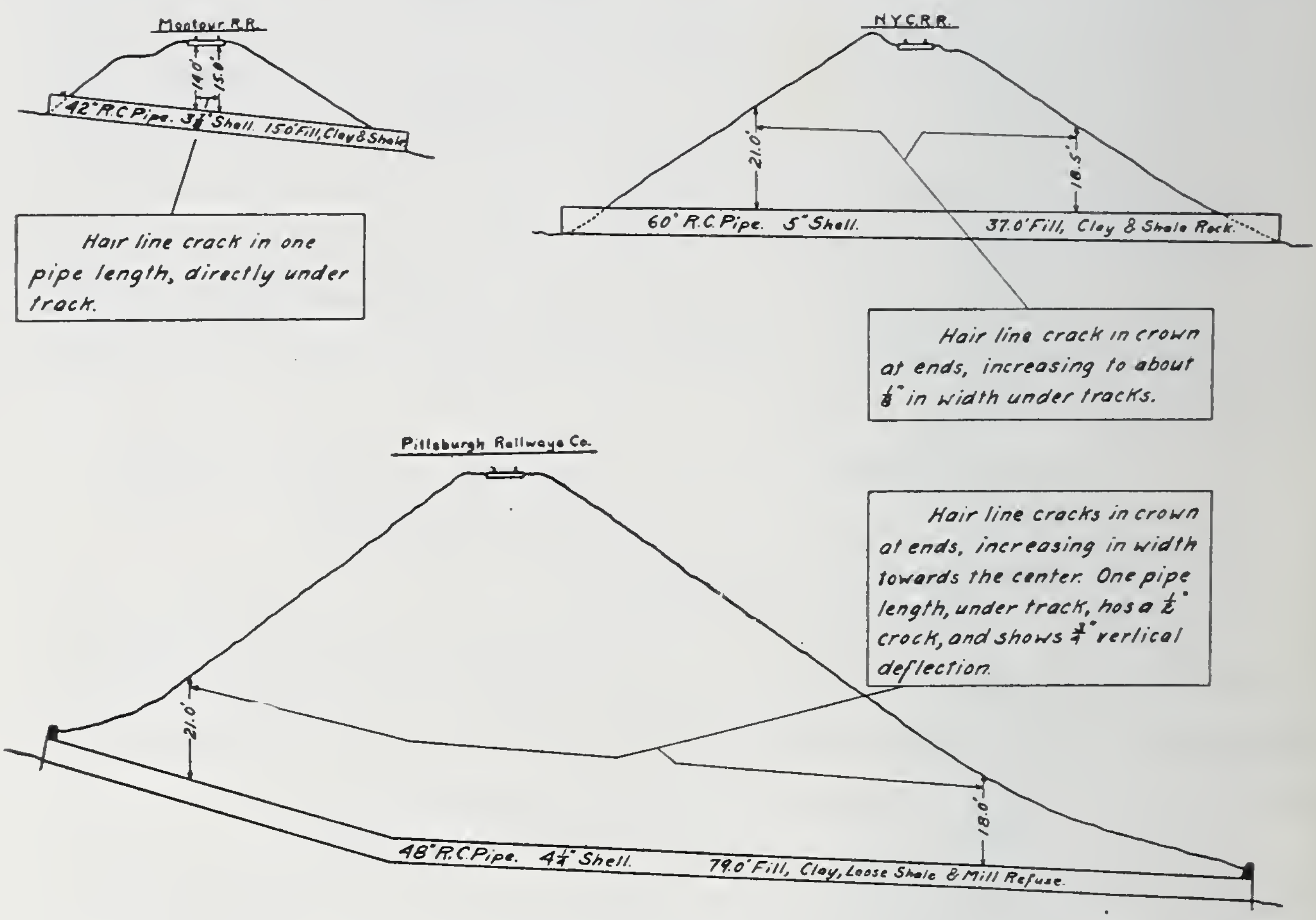


Fig. 4. Reinforced Concrete Pipe Culverts, Showing Tendency to Crack Under Fills.

culverts here shown were all designed for a uniform vertical load of 2500 pounds per square foot without crack, and 5000 pounds per square foot ultimate load, no allowance being made for lateral pressure. Cracks actually occur in each case under expected loads but although the highest fill must produce at least three times as great a load, the ultimate strength, due to lateral pressure, has not been reached. This lateral pressure consists primarily of the thrust of the fill against the rigid pipe structure, up to the point where cracking occurs. Beyond this point, the deflection of the

pipe increases rapidly, exerting a greatly increased reacting lateral thrust against the fill which may eventually become as great as the vertical load itself. In this condition, the pipe can continue to support increased heights of fill without any additional degree of failure. These pipes should never have been installed under more than 20 feet initial fill. I am confident that they are typical of many cases, not so subject to investigation, and which indicate the necessity of more thorough engineering supervision. Concrete pipe under ground is in an ideal condition to gain strength rather than lose it. Consideration of the above facts indicate that an exceptionally small factor of safety will prove satisfactory for concrete pipe-lines under external load, if proper engineering attention is paid to the details. The American Society for Testing Materials, with the Iowa tests as a basis, has approved a factor of safety of 1.5 as being satisfactory and sufficient for sewer-pipe.

In the same society's specifications for plain cement sewer-pipe, certain shell thicknesses and test loads are required, and in order to meet these requirements, the concrete must develop a modulus of rupture in flexure of 1050 pounds per square inch. Manufacturers of machine-made cement pipe are meeting this test without difficulty, and in many instances, far exceeding it. Tests at Pottstown, Pa., in January 1921, on machine-made pipe showed the following results:

Diameter of pipe in inches	No. of tests	Age when tested in days	Modulus of rupture Max.	Min.	Avg.
12	9	7 to 30	1773	1050	1316
15	10	4 to 28	1629	972	1277
18	8	7 to 30	1333	1040	1171
21	9	7 to 30	1182	901	1025
24	20	5 to 28	1396	902	1133
30	3	80	1544	1390	1465

Tests made at the University of Arizona (their Bulletin No. 86) on pipe three to four months old gave the following averages:

Diameter in inches	Average modulus of rupture
12	1067
16	953
20	904

This latter pipe was all made on a packer-head machine, which will be described later, but of which the Bulletin says, "The smaller the pipe, the better and more densely it was packed. This is perhaps characteristic of packer-head pipe and indicates that the packer-head principle is better adapted to small sizes of pipe than to large sizes."

Before proceeding to a discussion of reinforced pipe design, it is desirable here to call attention to a definite fact as demonstrated by the above data, and as recognized in the use of all plain cement pipe: *Concrete, of the character used in plain, machine-made, cement sewer-pipe, develops considerable tensile strength in flexure, which is taken into consideration in the design.*

Cast concrete will not develop over two-thirds of the flexural strength of machine-made concrete. In the Arizona tests, only about three-fifths as much strength was developed.

A comparison will now be made between a plain pipe, of machine-made quality, and the same with reinforcing added.

Assume a plain pipe, 48 inches in internal diameter with a four-inch shell, a modulus of rupture of 1050 pounds per square inch, and resisting moment per foot $= 1050 \times \dfrac{12 \times 4^2}{6} = 33{,}600$ inch pounds. Adding one per cent. reinforcing, placed one-inch from the surface, and, by ordinary principles of reinforced design, for equal strength: $7/8\ A\ f_s\ t = 33{,}600$ inch pounds, and, solving for the steel stress, $f_s = 35{,}500$ pounds per square inch.

This is slightly in excess of the yield-point of mild steel, and since reinforced concrete reaches its ultimate strength when the steel reaches its yield-point, *the addition of steel does not increase the strength of this pipe by the ordinary principles of design.* (Were the shell thicknesses such as would compare with ordinary reinforced beam depths, and the concrete of "cast" quality, the results would be quite different.)

The theoretical working stress in this steel would ordinarily be 16,000 pounds per square inch. The comparable extreme fiber stress in the concrete would be 475 pounds per square inch, and

the actual stress in the steel, at half the distance from the neutral axis and with 10 times the modulus of elasticity would be only 2375 pounds per square inch. With the concrete acting in tension, the steel increases the working strength of the pipe only about 11 per cent. at an increased cost of manufacture of approximately 60 per cent. The same result could be obtained by omitting the steel and using a shell 4¼ inches thick at an increase in cost of but seven per cent. (This does not include overhead or freight charges.)

In ordinary design of reinforced concrete flexural members, it is a recognized fact that the concrete on the tensile side of the member is cracked, even under safe loads, near the points of maximum moment. Since pipe-lines may carry liquids which would subject exposed steel to corrosion, and, since the first crack will in all probability occur along the invert of the pipe, it is of fundamental importance that this crack be prevented under the expected loads. This necessarily involves consideration of the tensile strength of the concrete in flexure.

We are now ready to advance new and rather unique principles of reinforced concrete design, as applied to the design of pipes, and which are thoroughly consistent with test results:

The design for working load shall be based upon the modulus of rupture of the concrete, and shall be such that the concrete will not crack under the load. The steel acting with proportionate stress, according to its position in the shell, may be figured in determination of the resisting moment. The design for ultimate load, which will be from 1½ to 2 times the working load according to the factor of safety adopted, shall be based upon the steel, stressed to the yield-point, with the concrete considered as cracked and incapable of taking any tensile stress.

The reinforcing in pipe may consist either of plain rod rings, wired to, and held in place by longitudinal bars; some type of mesh fabric; or continuous spirals. The latter offers a distinct advantage in that there is no distortion or weakened section due to lapped reinforcing.

Several methods of placing the reinforcing are possible. In Fig. 5, sketches *a* and *b* show single and double concentric rings.

The single ring should be used only in small-size pipe in which the shell is not sufficiently thick to permit the use of two rings.

Owing to its position in the center of the shell, it is inactive until the concrete has cracked and is, even then, not very efficient. A plain pipe designed for the same ultimate load would be far more economical.

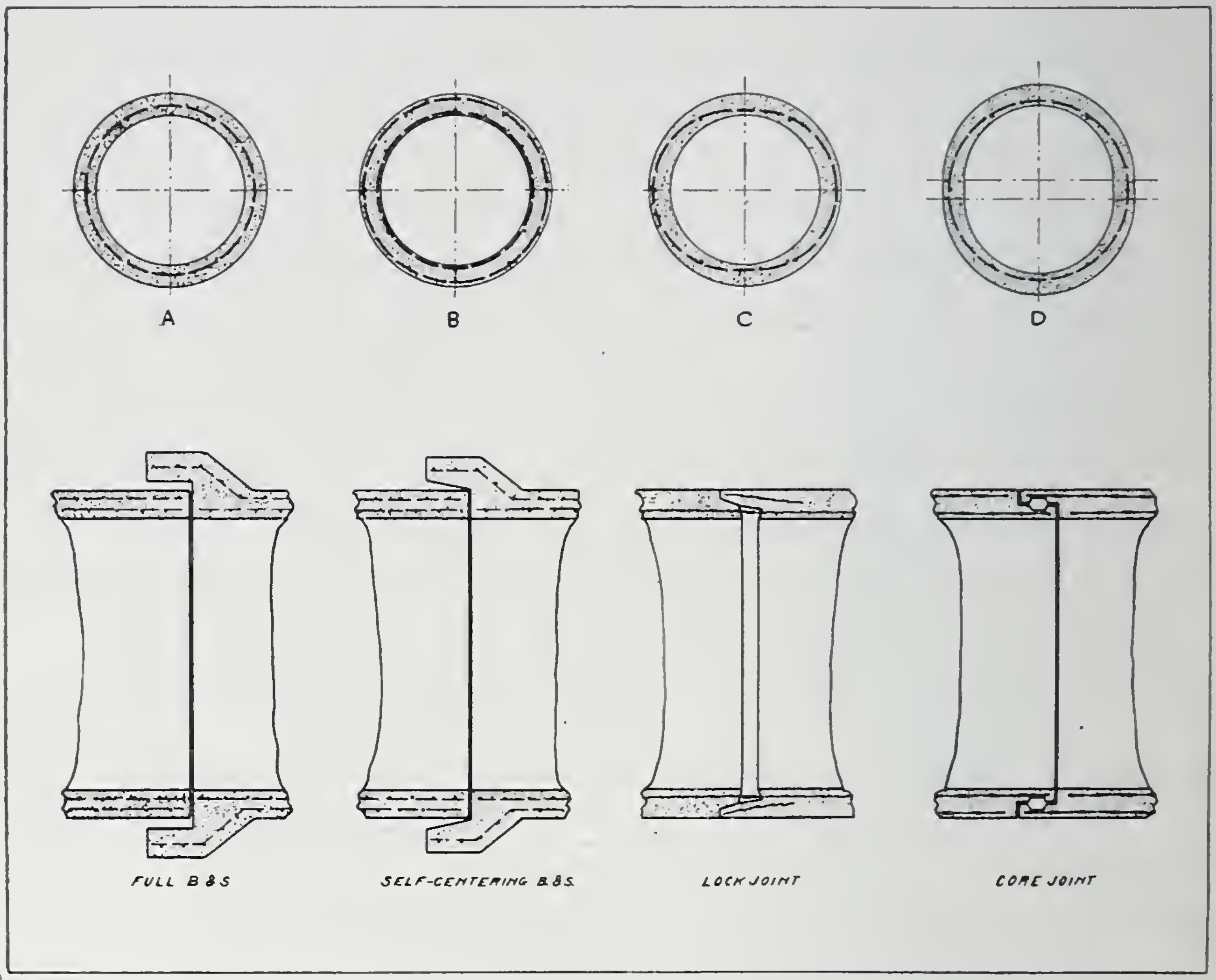


Fig. 5. Various methods of Steel Distribution and Details of Various Joints.

With two rings, the inner ring acts at the crown and invert, and the outer ring at the haunches, in taking tensile stress due to a vertical load. This system is equally effective in resisting loads at any angle.

Sketches *c* and *d* accomplish the same results for vertical loads with a single line of reinforcing. The steel in *c* being in an oval shape, is under initial strain when placed in the pipe form and is difficult to hold in proper position. A much more serious objection is the fact, that, if the pipe should be rotated 90 degrees from the position shown, the reinforcing becomes totally ineffective and might as well have been omitted.

The design shown in *d* is much less liable to the latter criticism, since the pipe is oval, and, if the first section be placed in proper position, the rest must follow suit in order to fit the joints. Conversely, if the first section is wrong, they are all wrong. This type of pipe is usually marked "TOP" at the extremities of its longer axis to prevent the possibility of the above blunder. Should the heaviest thrust on the pipe be in some other direction than vertical the reinforcing in sketches *c* and *d* loses much of its effectiveness. The bending moment in oval pipe is from three to five per cent. greater than in round pipe for equal loads.

There is a great variety in the types of joint used. (See Fig. 5.) The familiar full bell and spigot, so common on cast-iron and clay pipe is extensively used on concrete also. A very desirable modification is shown in the "self-centering" joint. This is not practicable in either cast-iron or clay, as it calls for a truly circular section and these materials are subject to considerable warping. Its advantage lies in the fact that a continuous straight line of invert is obtained when the spigot is shoved into its seat. Irregularities of the invert, with small dams formed at each joint, will offer more resistance to flow that minute roughness of the surface. In spite of careful inspection, it is next to impossible to prevent the occurrence of many such dams when using ordinary full bell and spigot pipe. The use of self centering joints will permit a reduction of *n* from 0.015 to 0.013 in Kutter's Formula, or similar reduction where other coefficients are used. The bell and spigot in large pipe may be modified so that no projection beyond the barrel of the pipe occurs. This offers advantages in manufacture, shipping, and laying that are of considerable importance. Some special modifications of this type of joint are shown in the "lock joint" and "core joint", both of which are patented features. These provide a certain degree of structural continuity in the pipe-line, due to the overlapping reinforcement, or cement-grout key placed in the joint. The joint in large size "lock joint" pipe is filled from the inside. Small "lock joint" pipe and all "core joint" pipe joints are filled with cement-grout, poured through a hole tapped in the top of the bell after the pipe is placed in position. A metal band is placed on the inside of the joint during this operation. The perfect joint, to which no objection can be found, remains to be developed.

Mention has already been made of two types of pipe—"cast" and "machine made." "Cast" pipe is pipe in which the concrete mix contains sufficient water to permit of pouring into the forms and compacting without other aid than rodding, hand tamping, or the use of jigging platforms. The comparatively narrow space into which the concrete must be poured, sometimes obstructed by two lines of reinforcing, calls for considerable fluidity of the mix if a smooth continuous shell is to be obtained. Such a pipe must be left in the forms at least until permanent set has taken place. The amount of water used in the mix is considerably in excess of the amount required for hydration and the resultant concrete is thereby weakened. All field-made pipe is necessarily of this type.

"Machine-made" pipe is manufactured upon two different machine principles. One machine, known as the packer head, is serviceable only for pipe up to 30 inches in diameter, being much more efficient in the smaller sizes. The packer head is a cylinder, in diameter equal to the bore of the pipe, surmounted by a set of outwardly deflecting vanes, and, in some cases, a pair of wings exerting downward pressure. This head is inserted centrally in the outside pipe form, and revolved as the concrete is fed in from the top. As it revolves, it rises through the form, the vanes press the concrete downward and outward to form the shell, and the cylinder following trowels the inside surface. Various machines differ in detail as to the moving parts, but the general principle of all is the same.

The other type of machine, known as the power tamping machine, is applicable and equally efficient for all sizes of pipe. In general, the machine consists of an external form revolving around a stationary metal core. The concrete, fed in from the top, is packed by power tampers acting at a high speed and exerting several hundred pounds pressure. The tamping occurs on successive layers only an inch or two thick and covers the complete surface of each layer. The outer form, revolving, carries the concrete with it, and the stationary core acts as a trowel against the moving surface. When the form is filled, the core is drawn out. With either type of machine, the pipe, still incased in the outer form, is then removed to a curing chamber where the form is stripped from it, leaving the pipe standing upon a ring pallet

which formed the bottom of the mold. The entire mold, with the exception of the pallet, is now ready to be used over again.

It is quite evident that the mix used in these machines must be of a stiff, self-supporting consistency or the pipe would slump upon removal of the form. There is danger of using too little water, and thus obtaining a mix which, while it will stand up perfectly, is too dry and will not develop much strength. Whether sufficient water for hydration has been used is always possible of determination by an examination of the exterior surface of the finished pipe. If too dry, the pipe will show a smooth, granular, porous structure, while a pipe made of concrete containing the proper amount of water will be covered with a web of honeycomb like markings, caused by the suction on removal of the outer form.

It is possible with proper use of this machine to obtain pipe at least 50 per cent. stronger than can be obtained by the ordinary casting methods. These machines originally used but a single tamper, and were unable to tamp effectively a shell containing reinforcing. Recently, multiple tampers have been introduced thus making possible the tamping of concrete on each side of, and between, the lines of reinforcing.

It is impracticable to attempt to fix upon any definite proportion of aggregate and cement for concrete pipe. With thin shells in small sizes, the use of fine aggregate only is possible, and, naturally, a rich mix is necessary. With larger pipe and thicker shells, coarse aggregate can be introduced—the maximum size being limited to about ¾-inch due to the small clearance around the reinforcing. Increasing the percentage of coarse aggregate reacts favorably upon the strength and absorptive qualities of the pipe even with leaner mixes, but is detrimental to a permeability test.

The manufacturer should be allowed considerable latitude in the questions of mix, shell thickness, and amount of reinforcing, as these may economically be varied among themselves to obtain equally satisfactory results to the purchaser. Control of the results can best be regulated, to the satisfaction of all parties concerned, through comprehensive and thorough tests of the finished product.

The usual tests for concrete pipe consist of load test, absorption test, and hydrostatic test. The load test has been subject to material change in the method of application, during the last 20 years, and is now practically standardized along lines of thorough reliability.

In early tests, it was customary to support the pipe in a rigid cradle while the load was applied through an equally rigid saddle. The result was that the load depended more upon the strength of the supports than upon the pipe structure. The load concentrates at the quadrant points and, as shown in Fig. 3, produces but slight bending moment, being supported largely by compression in the sides of the pipe.

In other tests, bags of sand or cement were piled around and over the pipe; or the pipe, between heavy timbers, was surrounded by sand and the load placed upon this sand bed. These latter methods develop an unknown amount of arch action relieving the load on the pipe.

In recent years, the tendency has been to concentrate on three tests which have been standardized by the American Society for Testing Materials, and are known as the "two-point", "three-point," and "sand-box" bearing tests.

In the two-point test, the bearing strip is of steel, one inch wide, with a cap of plaster of Paris to take care of inequalities in the pipe surface. It is difficult to obtain the proper balance on this strip in testing large pipe, and the plaster bed tends to squeeze out under the pressure of the pipe weight when placed in position.

The three-point test consists of a single line bearing at the top and two line bearings centered two inches apart at the bottom, no plaster bed being used. No difficulty in obtaining a balance on the lower bearing is encountered, and any marked inequalities in the surface can be removed with a chisel if they project, or, if concave, can be filled out with metal liners. Due to the two bearings at the bottom, there will be a slight error in the calculated bending moment as deduced from the formula for concentrated load. This will not be appreciable for large pipe and is negligible for small pipe on account of the disproportionate shell thickness in these sizes.

The sand-box test was devised and extensively used at Iowa

State College in tests on concrete pipe, and is frequently called the "Iowa test." In this test, the upper and lower quadrants of the pipe are bedded in sand. The upper sand bed is contained in a rigid box. Strips of cloth along the lower edges prevent the escape of sand and keep the box from bearing against the pipe. The load is applied uniformly to the upper sand bed. This test has been found to produce upon a pipe effects similar to that of an equal load of ditch filling, and for this reason it has been strongly recommended as a logical test for sewer-pipe. From what has already been said, it is evident that the test does not represent the conditions of a fill and, as a general pipe test, it is subject to the criticism that the arching action in the sand is likely to cause a concentration of loading at the quadrant points where it produces a comparatively small bending moment. Since the box is built to resist lateral deflection, it offers an indefinite amount of lateral resistance to pipe deflection. Tests have shown that the moment produced varies materially from the theoretical value for a uniform quadrant load, and the empirical formula $M = 0.10W'd$ has been adopted.

For a thoroughly reliable test of the pipe structure, and one subject to analysis, the two-point or three-point bearing tests are to be preferred over any others yet devised. I have, however, one criticism of the arrangement for these two tests—the point of application of the load is at the center of the bearing which rests on the barrel of the pipe, only. The bell is not loaded. In testing plain pipe, the failure is practically instantaneous and its progress cannot be noted. In studying the progress of failure in reinforced pipe, it will be found that the crack usually begins at the spigot end and progresses through the body to the bell, indicating a heavier flexural stress at the spigot end. By moving the point of application of the load nearer to the bell, so that it is more nearly over the center of resistance of the pipe shell, an increase of from 10 to 20 per cent. in the supporting capacity of the pipe can be obtained with an instantaneous crack from end to end when the critical load is reached. The three-point test is generally preferred by the eastern railroads and state highway departments in testing culvert pipe.

Fig. 6 shows method of testing five-foot, reinforced concrete, railroad-culvert pipe with three-point bearing at the United States

Bureau of Standards laboratory in Pittsburgh. This series of tests covered reinforced pipe, three, four, five and six feet in diameter. The pipe was shop made, of cast concrete with shell thicknesses varying from 3.5 inches for the three-foot, to six inches for the six-foot pipe. The pipe averaged $1000D$ pounds per foot

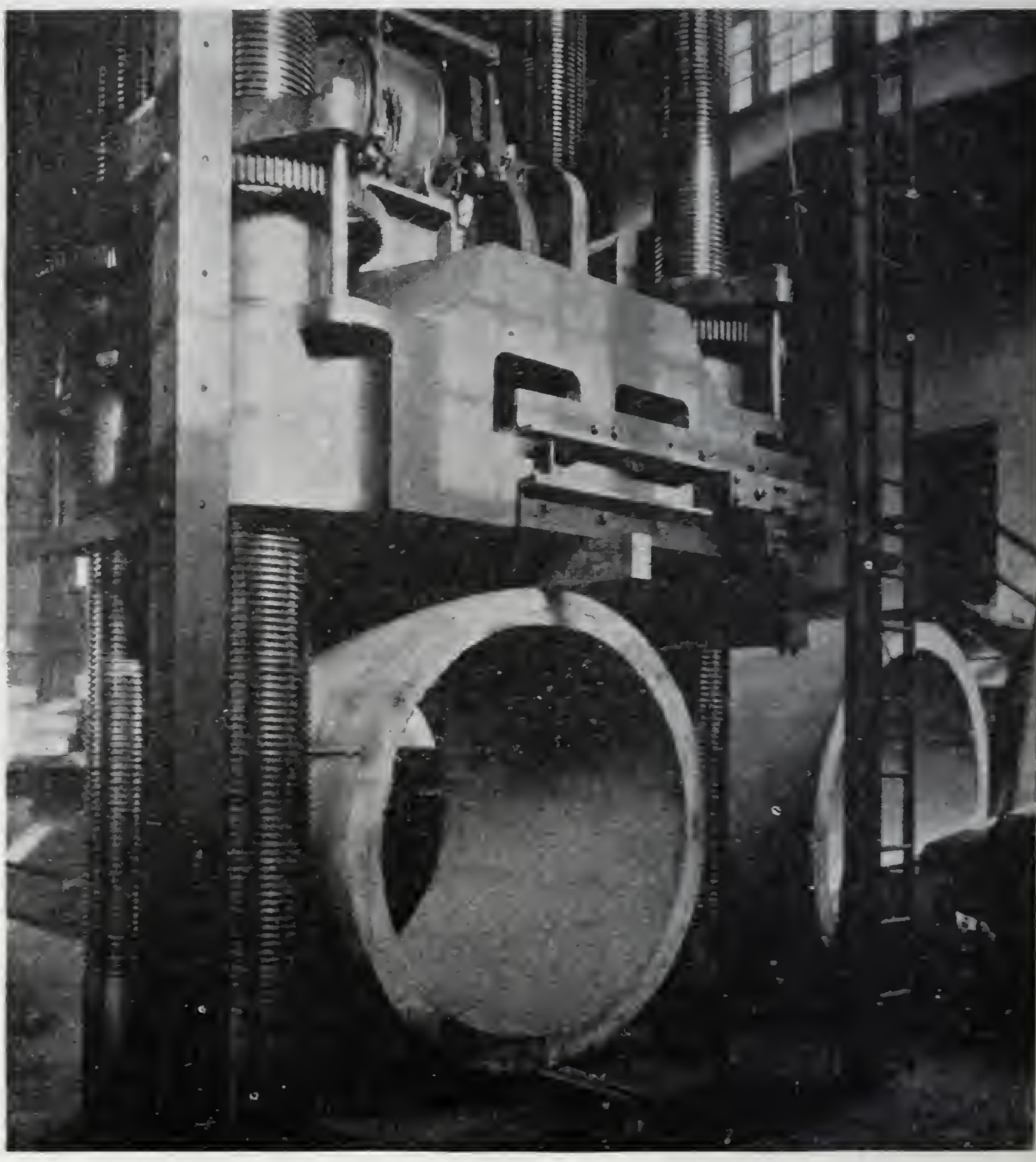


Fig. 6. Testing Reinforced Concrete Pipe.

load at the first crack, and from $2000D$ pounds to $2500D$ pounds ultimate load (D being the mean diameter of the pipe, in feet). The modulus of rupture of the concrete varied from 652 to 742 pounds per square inch, averaging 691 pounds per square inch.

In the absorption test, a thoroughly dried sample of concrete, broken from the pipe, is immersed in water at room temperature for a period of 48 hours, or is immersed in boiling water for five hours. Concrete will absorb but very little additional water in periods of immersion longer than 48 hours. The boiling test is supposed to produce an accelerated effect, but seems to produce increased absorption over ordinary immersion regardless of the length of time allowed. The percentage increase in weight should not exceed six per cent. after ordinary immersion or eight per cent. after boiling. Low absorption is accompanied by high resistance to action of acids and alkalies.

Hydrostatic tests are for the purpose of determining strength, in the case of pressure pipe, and determining permeability of gravity pipe, particularly sewer-pipe. The pressure in a permeability test is limited to 15 pounds for 30 minutes. The pipe should not show any leakage at the end of the test. Occasionally beads of water or even a slight trickle will appear during the progress of the test. If this has disappeared at the conclusion, it is not considered detrimental.

The importance of tests cannot be overestimated in an endeavor to obtain and maintain a high quality of pipe. It is too frequently the case, that, although called for in the specifications, they are omitted as being too troublesome to perform. It is of great importance, to the manufacturer as well as the engineer and the consumer, that this condition be remedied so that, through a better and more comprehensive knowledge of the principles governing the design, manufacture, and use of concrete pipe, a more efficient service can be rendered by this rapidly growing industry.

DISCUSSION

Mr. J. M. Rice:* As a water-works engineer I am very much interested in the question of the heads for which reinforced pipe has been developed. Also, I would like to know whether it has proved practicable to put a shell of wrought-iron or steel pipe in concrete; what protection would be secured by the pipe being in concrete; and whether you could put a mesh on the outside of the steel pipe and get better results shooting gunite or by casting concrete around the pipe.

Mr. Joseph S. Lambie: Reinforced concrete pressure pipe has been used extensively in this country for heads up to 180 feet. As already stated, it has been tested in England under a 450-foot head, but this pipe had a sheet-metal core. Such pipe is not manufactured in this country. Sometimes steel pipe is coated with concrete as a preservative, but such pipe is not reinforced concrete pipe. A coating of gunite applied to the surface of a steel pipe will prolong its life indefinitely. Preferably this gunite should be applied after a light wire mesh has been placed over the pipe surface. Results with gunite will be vastly superior to a cast coating.

Within the last few years there has been developed a process for making pressure pipe by the centrifugal process. The concrete is poured throughout the length of a rapidly revolving mold and by centrifugal action is compacted with great density on the walls of the mold. It is largely in the experimental stage as yet but promises great things. It offers the decided advantage of being able to use a wet mix and then remove the excess water. A difficulty is in the collecting of lighter and poorer ingredients of the mix upon the inside surface, where the best concrete is naturally desired. This coating must be removed to get a good pipe.

Mr. J. M. Rice: This English pipe has a reinforcement.

Mr. Joseph S. Lambie: Yes. It is spirally wound very much like pipe made to-day. The spiral winding provides the strength in tension and the sheet-steel core is intended only to assure impermeability.

*Consulting Civil Engineer, Pittsburgh.

Mr. H. R. Thayer, *Chairman*:* Have you any idea as to the leakage of concrete pipe?

Mr. Joseph S. Lambie: I have no data on that particular point.

Mr. H. R. Thayer, *Chairman*: In my general experience almost anything in concrete will leak at 180-foot head; the only question is how much you can limit it.

Mr. Joseph S. Lambie: The bulk of the leakage will occur at the joints. On much of the pressure pipe there are special metal joints which permit of adjustment and tightening to prevent leakage.

Mr. H. R. Thayer, *Chairman*: We would like to hear from Professor Smith of the University of Pittsburgh.

Mr. J. Hammond Smith:† I have nothing to add to the discussion, except that the statements of Professor Lambie regarding the method of loading pipe in testing, should be emphasized.

Loading the barrel of the pipe symmetrically, and allowing the bell to overhang without provision for its taking its share of the load (in accordance with A. S. T. M. specifications) is certainly not a fair test, nor one from which we can expect to secure consistent results. It is evident that the A. S. T. M. specifications relating to the testing of sewer-pipe need revision.

Mr. H. R. Thayer, *Chairman*: It seems to me the bell produces considerable additional strength, especially when it is cemented in with the rest of the pipe.

Mr. Joseph S. Lambie: I doubt if many people applying the two-point or three-point bearing test to plain concrete pipe realize its unfairness. The failure is so sudden that proper

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†Professor of Civil Engineering, University of Pittsburgh, Pittsburgh.

observations cannot be made. The test would be very materially improved if the bell could be loaded, but it is very difficult to get a line bearing against body and bell at the same time. In some specifications it is customary to remove the bell and test the straight barrel only. This is all right if the pipe is not injured in the process. I believe the simplest solution lies in moving the point of application of the load nearer to the bell end of the pipe.

Mr. B. A. Ludgate:* In the experiments made at Ames, Iowa, what means were employed to obtain accurate measurements of the intensity of the various loads in various directions as regards the pipe, and the stresses produced in the pipe when placed in a trench or fill?

Mr. Joseph S. Lambie: In the case of a trench, a section of sewer-pipe, placed between, and supported by, end gate walls, was placed in a trench and the backfill made between the end gates. The load supported by the end gates was measured by a leverage system and platform scale on the ground above. In the fill there were retaining-walls built up at the ends of a culvert 20 feet long. Each two-foot section of the culvert was independently supported on a lever, fulcrumed on a solid concrete foundation and supported at the outer end, which was beyond the retaining-wall, on a platform scale. There is a question in my mind as to the accuracy of measuring static earth pressures on any type of balance scale. To measure on a balance you must have movement, and when the balance is struck you are either raising or lowering the mass of superimposed earth, and are consequently including either positive or negative frictional forces in your measurement and not simply the static pressure. If a pipe were to be accurately gaged for deflections under various known loads, the actual intensity of static pressures under conditions of use might be determined by observations of deflection.

Mr. Wallace S. Brown:† In manufacturing various pipe is a definite amount of water used?

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†Carnegie Steel Co., Duquesne, Pa.

Mr. Joseph S. Lambie: In manufacturing cast pipe the manufacturer can use any quantity of water he has a mind to, with very marked effects upon the strength of the pipe. The mix must be rather wet in order to get it into the form. In machine-made pipe there is a very narrow limit within which you can vary the amount of water. With too much water the pipe will not stand up on removal of the forms.

Mr. Wallace S. Brown: Is it accurately measured?

Mr. Joseph S. Lambie: It must be accurately measured for machine-made pipe. A quart of water more or less will either make the pipe slump or appear granular and dry. The amount is far less than is used in cast pipe and results in greatly increased strength and wearing qualities in the concrete.

Prof. F. M. McCullough:* I was interested in the computation of the modulus of rupture. Was the method based on a pipe section or a beam section?

In reinforced concrete pipe, is the working load such that the concrete is not cracked in tension?

Mr. Joseph S. Lambie: The modulus of rupture is calculated from the flexure formula for beams and the theoretical bending moment for the type of load used. The original curvature of the pipe section as it affects the strains under load is ignored in both cases and is therefore probably compensating. It is generally believed that the concrete should not be cracked in tension under the working load, but the usual methods of design based on a working stress in the steel give no assurance that this is actually the case. I have endeavored to point out this evening a new method of design, based on the strength of the concrete, which will guard against cracks. It is the only practical way in which this can be accomplished. It is sometimes quite difficult to tell when the first crack forms. This is particularly true with the rough tests in which a direct load is applied. With a hydraulic or

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counterbalanced testing machine there is a noticeable jump in the gage pointer or balance arm when the crack occurs. This is due to the sudden transfer of stress to the steel and a momentary let up in the resistance of the shell. If you stop the test at this point and have good enough eyes and hunt long enough you can invariably find the crack. With a direct load the crack will not be noticed until it begins to open up, which will not be until the steel has reached its yield-point.

Prof. F. M. McCullough: Are those cracks determined by the water-mark method or by the eyes aided by a reading glass?

Mr. Joseph S. Lambie: They are subject to direct observation by the naked eye, if good enough, as a very faint continuous hair line. A magnifying glass will help. Sometimes when in doubt as to whether actual cracks have formed, I have marked their supposed location to check against the open cracks later in the test.

Prof. F. M. McCullough: Isn't it possible that still finer cracks might exist before?

Mr. Joseph S. Lambie: I think they would be indicated by the machine unless present at the beginning of the test. I always had difficulty in determining when cracking did occur until I noticed the sudden drop and recovery of the balance arm. Since then I have made minute examinations both before and after this drop in a number of tests and have always found the crack to be coincident. The beam will act as a reliable telltale for any transfer of stress from concrete to steel, and should automatically record any cracking that occurs.

Mr. P. J. Freeman:* I am glad to hear the speaker recommend the benefits of testing, because I am interested in testing.

At this time, I would like to ask if there is anyone here who knows of a machine that has been designed for accurately testing

*Chief Engineer of Tests, Pittsburgh Testing Laboratory, Pittsburgh.

concrete pipe. There is a considerable demand for such machines, which can be sold at a reasonable price, and yet be sufficiently accurate for the purpose. We received a telegram to-day from Texas, requesting information concerning such a machine, but we were unable to furnish the desired information. I understand one or two are being designed in Pittsburgh.

We find from our inspection of pipe over the country that there is a tendency on the part of engineers to push up their requirements for strength, hoping to get a better product, but perhaps the pipe is thus made to cost more money than it should for the service required. The speaker pointed out that we have certain specifications and really don't know how to use them. One of our inspectors just sent in word that the engineer had added a few hundred pounds more to his requirements. The manufacturer will of course raise the price to correspond. Is the engineer getting any better pipe for the service than if he had stuck to his old requirements? He is basing everything on strength, which is only one of the things desirable in concrete. We must have impermeability, regardless of the strength of the concrete. We have the absorption test in our specifications, but many engineers do not think as much of it as they did a few years ago. It has been found from an extended investigation that tile having the highest impermeability will show the greatest resistance to disintegrating agents, but the absorption tests do not indicate this difference. The difference in permeability may be due to a greater amount of cement or the methods of manufacture. It seems possible that the rate of absorption might be used as a measure of durability, but the ordinary absorption value alone does not seem to indicate the necessary qualities for resisting disintegrating agents.

The United States Bureau of Public Roads has been making a number of impact tests and has found that the impact on a road from a truck is about seven times the static load. In using pipe of any kind for culverts, which are not paved over, will there be any effect on the tile from impact? I notice in your curves that the American Railway Engineering Association does recognize impact in its specifications.

Mr. Joseph S. Lambie: Rate of absorption is closely related to permeability. On the west coast the hydrostatic pressure test for permeability is considered the most important of all pipe tests. A pipe that contains a large amount of fine aggregate is likely to pass a poor absorption test and a good permeability test. The opposite is true of a pipe containing coarse aggregate. A permeable pipe will have a porous, open structure, quite subject to disintegration by alkali action where such soils occur. I believe that the question of impact will be considered by the Joint Committee in due course. They are endeavoring now to straighten out this question of earth pressures and, until they get somewhere with that, will probably not confuse the issue by a consideration of impact. Since, when impact occurs, there is little earth load, and with a large earth load or fill there is no impact, it is probable that a single standard can be obtained that will be satisfactory in either place.

You spoke of engineers increasing their strength requirements. They are not doing it with any great degree of system. A failure occurs and they assume that the pipe is not strong enough, when it is quite possible that it is being used under conditions for which it was never intended. A standard pipe should not be designed for all possible conditions. It would be a tremendous economic loss to do any such thing as that. Normal conditions should be the basis of normal pipe design, and special, or extra-strength pipe supplied for any special cases. This condition is well recognized in the cast-iron pipe field and the pipe standardized in several grades accordingly.

Mr. C. F. Buente:* I would call attention to the present rather unsatisfactory manner of classifying concrete pipe. As demand has been created, concrete pipe have been designed and manufactured for use in sewers and in highway and railroad culverts, the strength of each of these classes of pipe increasing somewhat in the order named. Pipe of each kind is used almost exclusively for the purpose originally intended, and presumed to cover all conditions of loading when so used. It is at present

*Consulting Engineer and Secretary, Concrete Products Co., Pittsburgh.

difficult to secure the use of highway culvert pipe for sewer purposes when the depth of sewer would warrant the use of pipe of greater strength than the pipe known as sewer-pipe; just as, under similiar conditions, it is difficult to secure the use of railroad culvert pipe under highway embankments. This inelastic method of classification of course has led to some failures of concrete pipe.

The Joint Committee to which Professor Lambie has referred will undoubtedly rectify this situation. In all probability this Committee will classify pipe according to its load carrying capacity rather than according to the use to which it is applied, and probably in a manner similar to the present classification of cast-iron pipe.

Referring to the question of pipe testing, I would like to ask Professor Lambie if this problem could not be solved by designing a testing machine that would produce a uniform deflection throughout the full length of the pipe.

Mr. Joseph S. Lambie: That would solve the difficulty nicely. In our tests at the University of Pittsburgh, the load was applied at the center of the bearing resting on the body of the pipe. The crack started at the spigot end and progressed through the body to the bell. The deflection was markedly greater at the spigot end. In the tests at the United States Bureau of Standards, the bearing rested only on the body of the pipe, but the crack, as nearly as we could tell, occured coincidently from end to end. This was due to the fact that the pipe, placed entirely inside of the machine, rested on a bed-plate approximately six feet square, while a similar head transferred the load to the upper bearing. As the head and base approached each other in parallel planes, the pipe was deflected uniformly. Consequently strain, stress and load were all uniform. Any type of machine or method of loading which will produce uniform deflection in the pipe should give equitable test results.

Mr. J. S. Martin:* Have tests been made on other shapes than circular pipe, and if so, how do they compare with the circular form?

*Structural Engineer, Philadelphia Co., Pittsburgh.

Mr. Joseph S. Lambie: Tests have been made on oval pipe, but as far as I know the results are not available. Theoretically, the oval pipe must carry slightly greater bending moments than round pipe for the same loads. As I recall it, the amount is only about three per cent. and is not important.

Prof. C. G. Dunnells:* I understood the speaker to say that in designing concrete pipe a factor of safety of 1½ had been used. Is this the common practice?

Mr. Joseph S. Lambie: There is no common practice, and that is one of the reasons why I mentioned several of the points in this talk to-night. A factor of safety of 1½ is sufficient if you know the loads to which the pipe will be subjected. The American Society for Testing Materials has approved a factor of 1½ for sewer-pipe. That assumes there is an engineer on the job who knows his business. The New York Central Railroad asks for a factor of safety of 5 in the design of its culvert pipe. Such a design would be absolutely impracticable.

Mr. Wallace S. Brown: Does the manufacturer now manufacture according to the load the pipe is supposed to carry or is there a standard?

Mr. Joseph S. Lambie: It has been the custom to manufacture standards according to use and not to load. Thus there are so-called "sewer-pipe", "highway culvert pipe", "railroad culvert pipe", etc. This is all wrong. Standardization should be upon a load-carrying capacity. Some manufacturers will specify the load which the pipe will support, and the engineer should ascertain this and be governed thereby rather than by a name. It is the job of the Joint Committtee to standardize pipe upon some such basis.

Mr. J. M. Rice: Cast-iron pipe was first cast in six-foot lengths. Now it is made up in 12 and 16-foot lengths. Is there any limiting factor to the length of a concrete pipe.

*Head, Department of Building Construction, Carnegie Institute of Technology, Pittsburgh.

Mr. Joseph S. Lambie: The only limiting factor is the facility for handling and for transportation. Pre-cast concrete pipe has been made in lengths varying from two to 20 feet. From four to eight feet are the most common lengths Pipe frequently must be installed between trench lagging braces or between railroad tracks, and short lengths of four to six feet are desirable. Some contractors object to the weight of longer lengths, while others desire them on account of the smaller number of joints.

Mr. H. R. Thayer, *Chairman*: I would like to ask in regard to pressures. In laying pipe it is customary to tamp very thoroughly around the bottom. That should be done up to the springing line. That would tend to increase the lateral pressure and consequently the factor of safety. You assume that the load is vertical. That cannot be inclined to the surface of the pipe more than the angle of friction and this, for a smooth concrete pipe, is very low. The same question comes up in the design of arches.

In regard to earth pressure there has been a great deal said by learned men about the pressure of grain in bins. If you consider the earth pressure as inclined it increases the factor of safety a great deal. If the pressure is radial you would have a case of pure compression. The lateral pressure is only a fraction of the vertical pressure. About 30 years ago we used to design sewers up to 36 inches with a single row of brick four inches thick. That is interesting in view of the thickness you have named at the present time. Of course, brick-work would have only a fraction of the strength you get with a plain concrete.

Mr. Joseph S. Lambie: The lateral pressure intensity will probably be only about 1/3 or ¼ of that of the vertical pressure as long as the pipe is rigid. When the pipe cracks, it deflects materially. The normal lateral earth pressure is greatly increased due to this lateral expansive tendency in the pipe. Eventually you may get a condition with a failing pipe where the lateral and vertical pressures are equal and additional load will have no effect upon the pipe. Plain pipe cracked into four quadrants has frequently been found on excavating deep trenches, and is indicative of the condition above mentioned.

Mr. J. M. Dilley:* The idea is prevalent that the acidity of domestic sewage is harmful to concrete. On the other hand, domestic or sanitary sewage does not contain acids or gases that will affect standard concrete pipe. Analyses of sewage in representative cities in the United States and foreign countries have been made, showing that the chemical reaction is slightly alkaline, so that a well-designed mixture for concrete pipe properly made should show no disintegration.

Mr. Rudolph Hering, consulting engineer and sanitary expert of New York City, has stated that in an inspection of concrete sewers in Vienna, ten to twenty years old—where both small and large sizes had been built and the sewage was rather strong due to unusually small per capita water-supply—no signs of disintegration were found, but the surface looked dense and smooth.

Mr. Joseph S. Lambie: Concrete is not subject to disintegration by ordinary domestic or municipal sewage, although much propaganda would create a different impression. In large trunk sewers and in sewage disposal works this question is seldom brought up. The bulk of the discussion occurs where concrete is in competition with some other material. Cases which show disintegration of concrete due to sewage action will usually be found, on investigation, to be due to the formation of sulphureted hydrogen, and its condensation into concentrated acid on the exposed concrete surface above the sewage where the latter has become septic. There can be no question that concrete should not be used with strong acid solutions, but ordinary sewage seldom shows even the slightest acid reaction.

I have advanced several radical suggestions in reinforced concrete design. I hope it is distinctly understood that I am not approving these for general use, but only as they apply to the particular problem under discussion—the design of concrete pipe. In this particular field, existing methods have proved very unsatisfactory and results of tests show decided variation from what was anticipated, indicating that new methods are necessary.

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TESTING THE QUALITY OF LUBRICATING OILS*

By Winslow H. Herschel†

Introduction. There are two ways of buying oil, by brand and by specification. The former method must be used by those whose expenditure for lubricants is not large enough to warrant maintaining an oil testing laboratory. When oils are bought by brand it is in effect buying lubrication; that is, the price of oil includes engineering advice. It is known, however, that brands do not run uniform, and large consumers of oil usually prefer to employ their own chemists and lubrication engineers and to buy by specification. Government tests and specifications have been published.[1]‡

Not many years ago laboratory methods of test were used mainly for identification, to determine whether two samples of oil were alike or different, or whether an oil fulfilled the requirements of specifications. These specifications were written with the idea of procuring an oil that should be a Chinese copy of an oil which had proved satisfactory in service. For this purpose it was not necessary that tests should indicate the quality of an oil, and many of the tests which have come to be generally accepted do not indicate quality except perhaps indirectly. It is, of course, admitted that service tests are the court of last appeal, and laboratory tests can serve only to reduce the number of expensive and time consuming service tests required, but it must be remembered that service tests as well as laboratory tests are subject to misinterpretation.

I shall consider the various tests in use and indicate, as far as present knowledge permits, the extent to which each test is a measure or indication of quality; but it will be necessary first to consider what are the desirable qualities of a lubricant..

Properties of a Lubricant. Lubricants may be solid or fluid but are mainly liquids. A solid lubricant, like graphite, appears

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†U. S. Bureau of Standards.
‡See Bibliography at end of discussion.

to act by forming a smoother rubbing surface than that of the metal. A most striking example of this is furnished by the use of "aquadag" in drawing the tungsten filaments for electric lights.[1] The dies were once made as smooth as possible; now they are made purposely rough better to retain the graphite surface with which the tungsten actually comes in contact. It is now coming to be believed that a liquid lubricant, owing to its property of so-called "oiliness," has a similar effect in coating the rubbing surfaces with an adsorbed film of colloidal dimensions.

Under certain conditions of high speed and low pressure, air is an efficient lubricant, as shown by Kingsbury,[2] and by Harrison in the *Transactions of the Cambridge Philosophical Society*, 1913, vol. 22, p. 39.

For the most general condition of lubrication with a liquid, there are two régimes to be considered, that of complete film lubrication, at high speeds or low pressures, and that of incomplete film lubrication due to low speeds, high pressures, or inadequate supply of lubricant. In either case the necessary properties of the lubricant may be divided into two classes—those which assure that the lubricant will be suitable for the purpose at hand, when new, and those properties which indicate durability; that is, the maintenance of the original properties for a sufficiently long period of time in storage or in use.

The first essential of a lubricant is that it shall be fluid enough to reach the rubbing surfaces and viscous enough to remain in place and prevent metallic contact. The lower the coefficient of friction the better, provided it is not obtained at too great a sacrifice of factor of safety or durability.

The most commonly made tests are gravity, color, flash, fire, pour point, and viscosity, which will be considered in turn. Some of these indicate neither suitability nor durability.

Gravity. There is no relation between gravity and viscosity and on this account gravity has been discarded as a basis for fuel-oil specifications and fuel oil is now purchased by the government on viscosity. Similarly, there is no relation between gravity and volatility, and specifications for gasoline are based on a fractional distillation.

Gravity is a help in making an intelligent guess in regard to the source of the crude oil from which a lubricant is derived. According to Parish,[3] airplane motor oils may be divided into high specific gravity oils with a specific gravity above 0.9100 ("or 24 degrees Baumé conversion by the Tagliabue Manual 9th Edition, or below 23.85 degrees Baumé, conversion by the Bureau of Standards conversion table, Circular No. 57"), and low specific gravity oils with a specific gravity below 0.9100. The former are naphthene-base oils and the latter paraffin-base oils.

It is interesting to note in this connection that the long-standing discussion between the United States Bureau of Standards and the petroleum refiners concerning the modulus of the Baumé scale promises to be settled by the agreement between the American Petroleum Institute and the Bureau that the scale based upon the modulus of 141.5 shall be known as the A.P.I. scale and shall be applied only to petroleum products, while the scale based on a modulus of 140 shall be known as the Baumé scale and shall be reserved for other liquids lighter than water.

At the present time, when the market is full of mixed oils and oils from the mid-continent field, it is often impossible to describe an oil as either distinctly of paraffin or of naphthene base. It is believed that satisfactory lubricants may be made from any crude, and in government specifications, by the omission of gravity and by other means, care has been taken not to eliminate any satisfactory oil on account of its source.

Gravity has a legitimate use in determining absolute viscosity as it enters into the relation between absolute viscosity and the time of flow as measured in the most commonly used types of viscosimeters.

Color. The unwarranted emphasis put upon color may be partly due to the fact that the fatty oils, in use as lubricants before petroleum oils were put upon the market, were of light color, and color is a property easily observed. Refiners claim that they have to make oils of good color, whether they believe them of better quality or not, because the public demands it. Doubtless also refiners have educated the public to believe that a clear, light-colored oil is always of good quality. This is, however, not confirmed by test, and a water-white oil tested by the Bureau of

Standards was found both by laboratory and engine tests to be wholly unfit for use, as it gummed badly.

The government specifications for color are so lenient that it might be said they serve only the purpose of preventing the introduction of more stringent requirements. They are expressed in terms of the National Petroleum Association scale, but no method of testing is given. Numerous instruments have been used for measuring color and in some cases conversion tables are available between the different instruments.[4] It is believed, however, that the importance of color, for the consumer, is not great enough to warrant the use of elaborate apparatus, and the following method is suggested as sufficiently accurate for determining N. P. A. colors.

The use of solutions of potassium dichromate as color standards was suggested by Wertz[5] for varnishes and by Francis[4] for gasoline and kerosene. Table I gives potassium dichromate solutions necessary to match N. P. A. colors as determined at the Bureau of Standards. Where sulphuric acid is used as the solvent, the acid is poured into the water before the dichromate is added. The solutions change color on standing and must be matched immediately, with some oil used as a secondary standard, and discarded.

TABLE I. POTASSIUM DICHROMATE SOLUTIONS TO MATCH N. P. A. COLORS

N. P. A. color	Solvent	Grams H_2SO_4 per 100 cc. of acid	Grams potassium dichromate per 100 cc. of solvent
1.0	Water		0.0057
1.5	Water		0.0147
2.5	Water		0.0453
2.5	Water		0.0830
3.0	Water		0.1361
3.5	60% H_2SO_4	110.2	0.2910
4.0	"	"	0.4500
4.5	"	"	0.5330
5.0	"	"	0.6810
6.0	75% H_2SO_4	138.0	0.6800

Two sets of oils were used in matching—one of paraffin-base oils received from W. E. Perdew, Union Petroleum Company, Philadelphia, and one of mid-continent crude oils received from C. K. Francis, Cosden and Company, Tulsa, Okla., but no difference could be detected between the two sets. No set of N. P. A. colors of naphthene-base oils was available, but there was no

difficulty in matching such naphthene-base oils as happened to be at hand, and which varied from 2.0 to 3.5 N. P. A. colors.

The two acids used above were 60 per cent. and 75 per cent. by volume, of 95 per cent. acid. It is believed that Table I will apply equally well to oils of any base, and that it is accurate enough for all practical purposes. Extreme accuracy cannot be obtained by any method unless the samples are viewed in a standardized light.

Fire and Flash-Points. The flash-point is to some extent a measure of the volatility of the most volatile constituent and hence an indication of fire hazard and loss from evaporation. The flash-point of a blend, however, is higher than that of the lighter oil.[6] The weakness of the test is that it gives no indication of the amount of this volatile matter, which information can be obtained only by an evaporation test[7] or fractional distillation.[8] Unfortunately these tests have not been standardized or generally adopted.

The fire point serves as a check on the flash-point, too great a difference between the two tests sometimes indicating that the flash-point is incorrect because of failure to dry out the sample bottle after washing with gasoline.

Naphthene-base oils are as a rule lower in fire and flash-points than corresponding paraffin-base oils of the same viscosity. In the government specifications the fire point has been omitted and the flash-point has been kept low enough not to cause the rejection of oils from any crude.

Pour Point. The effect of cold upon an oil may be expressed as a melting-point or as a temperature of solidification, the present tendency being to discard the former and adopt the latter under the name of pour point.[9]

When machinery is to be used out of doors in winter, the pour point becomes of great importance. At lower temperatures the oil will not flow and hence cannot reach the rubbing surfaces. The pour test may therefore be regarded as an important suitability test.

There is no sudden change in consistency of oils at the pour point, as there is with water when it freezes; so that in cranking

an automobile, for example, the question may arise whether a very viscous oil at a temperature above its pour point offers more or less resistance than another oil which, at the same temperature, is below its pour point. The evidence appears to be that the viscous oil may offer the greater resistance because it winds about the shafts and sticks to them, while the oil which has solidified acts more like a grease, and "channels;" that is, a shaft or gear cuts a channel which does not fill up. As the machine continues to operate, the oil will heat until it ceases to channel, so that the temporary increase in friction due to lack of adequate lubrication will not be serious.

A very low pour point can be obtained only by the complete removal of paraffin, if originally present in the oil, so that the requirement of a low pour point may be more burdensome to some refiners than to others; yet when a pour point of minus 40 degrees F. is necessary, as for airplane machine-guns, it must be had regardless of expense. On the other hand, to specify a lower pour point than required may needlessly restrict competition and increase the price of oil.

Viscosity. A most important test for suitability is that for viscosity, although it is not a quality test at all unless viscosity is determined at two temperatures. All oils decrease in viscosity with an increase in temperature,[10] but some decrease more than others, and an excessive change in viscosity is undesirable. The addition of fatty oils in compounding decreases the change of viscosity with the temperature.

The standard temperatures are 100, 130 and 210 degrees F. Considering viscosity as a suitability test, the viscosity at only one of these temperatures is not a measure of quality. Porpoise jaw oil may be excellent for watches but it would be entirely unsuitable as an airplane motor oil, and, conversely, castor oil is a good oil for heavy work but unsuitable for sewing machines. For any given machine there is a viscosity of minimum friction, and the ratio of the viscosity of the oil film at the operating temperature to the viscosity of minimum friction, may be regarded as the factor of safety.[11] Wilson suggests that a suitable factor of safety is 5, and shows that the actual factor of safety attained in practice is inconsistent.

The viscosity is more completely under control of the refiner than any other property. Any desired viscosity can be obtained by blending, as in mixing a spindle oil with cylinder stock, which has however the disadvantage that the cylinder stock is not as readily filtered as an oil of moderate viscosity. Cylinder stock (so called because it is the basis of steam-engine cylinder oil) is not usually made from naphthene-base crudes, which however furnish unblended oils of higher viscosity than do the paraffin-base crudes.

The measurement of viscosity with accuracy presents numerous difficulties. It is known that after prolonged use, viscosimeters tend to show too high a time of flow. One explanation which is offered is that this is due to adsorbed films which accumulate in spite of the usual frequent cleaning of the outlet tube with gasoline. If this is the case, some better solvent such as benzol should be used. I am inclined to believe, however, that the increased time of flow is due to peening over the sharp corner at the upper end of the outlet tube by continual rubbing with the thermometer bulb, and that in the instruments having a stainless-steel outlet tube, this difficulty will not be experienced.

Whatever the cause of change in time of flow, absolute viscosity in poises, or Saybolt viscosity corrected to that obtained by a normal instrument, may be obtained by the use of Table II giving Bureau of Standards corrections for readings of Saybolt universal viscosimeters when A has other than the normal value of 0.00216 in the equation

$$\text{kinematic viscosity} = \frac{\text{viscosity in poises}}{\text{density, in grams per cc.}} = At - \frac{1.80}{t},$$

where t is the time of flow in seconds, or the Saybolt viscosity. The value of 1.80 is determined by the standard dimensions. The Bureau of Standards is prepared to issue certificates giving the A value, or to determine the kinematic viscosity of oils which may then be used to calibrate viscosimeters.

Viscosity is the last on the list of tests in common use. It will be seen after running through the list that none of these tests is found to throw much light upon the quality of the oil. Even the test for viscosity is deprived of its potential value by the custom of taking observations at only one temperature.

TABLE II. CORRECTIONS FOR READINGS OF SAYBOLT UNIVERSAL VISCOSIMETER

A Value		0.00210	0.00211	0.00212	0.00213	0.00214	0.00215	0.00216	0.00217	0.00218	0.00219	0.00220
Sign of correction		Minus	Minus	Minus	Minus	Minus	Minus	Plus or minus	Plus	Plus	Plus	Plus
Saybolt viscosity normal, *t*	Kinematic viscosity*											
32	0.0128	0.6	0.5	0.4	0.3	0.2	0.0	0.0	0.0	0.2	0.3	0.4
40	0.0414	0.8	0.7	0.5	0.4	0.3	0.1	0.0	0.1	0.3	0.4	0.5
50	0.0720	1.1	0.9	0.7	0.5	0.4	0.1	0.0	0.1	0.4	0.6	0.7
60	0.0996	1.4	1.1	0.9	0.7	0.5	0.2	0.0	0.2	0.5	0.7	0.9
70	0.1255	1.7	1.4	1.1	0.8	0.6	0.2	0.0	0.2	0.5	0.9	1.0
80	0.1503	2.0	1.6	1.3	0.9	0.6	0.3	0.0	0.3	0.6	1.0	1.3
90	0.1744	2.3	1.9	1.5	1.0	0.7	0.3	0.0	0.3	0.7	1.1	1.4
100	0.1980	2.6	2.1	1.7	1.1	0.8	0.3	0.0	0.3	0.8	1.3	1.6
125	0.2556	3.3	2.7	2.1	1.6	1.1	0.5	0.0	0.5	1.0	1.6	2.1
150	0.3120	4.0	3.3	2.6	1.9	1.3	0.6	0.0	0.6	1.3	2.0	2.5
175	0.3677	4.8	3.9	3.1	2.3	1.5	0.7	0.0	0.7	1.5	2.3	3.0
200	0.4230	5.5	4.5	3.6	2.6	1.8	0.8	0.0	0.8	1.7	2.6	3.5
225	0.4780	6.2	5.1	4.1	3.0	2.0	0.9	0.0	0.9	2.0	3.0	4.0
250	0.5328	6.9	5.7	4.6	3.4	2.2	1.0	0.0	1.0	2.2	3.3	4.5
275	0.5875	7.7	6.4	5.1	3.8	2.5	1.2	0.0	1.2	2.4	3.7	4.9
300	0.6420	8.4	7.0	5.6	4.1	2.8	1.4	0.0	1.4	2.8	4.0	5.4
Over 300 seconds, correction per 100 seconds		2.86	2.37	1.89	1.41	0.93	0.46	0.0	0.46	0.94	1.37	1.82

* Corrections are calculated for values of *k. v.* (kinematic viscosity) or for the *normal* Saybolt viscosity, but if the table is entered with values of *t*, *as run*, the error will be less than one second.

Other tests which give promise of indicating quality have been less frequently used and are consequently less thoroughly standardized. They are forced to win their way if possible against considerable opposition and it often becomes a question whether the burden of proof is on the consumer to prove that a test is of value, or upon the producer to prove that oils which would be rejected by the test are better than, or at least as good as, those accepted.

Oiliness. Another most important property which influences suitability is oiliness, which causes a difference in friction between two lubricants of the same viscosity at the temperature of the oil film, when used on the same bearing under the same conditions of speed and pressure. Oiliness has no effect when there is complete film lubrication, so that at first sight it would appear to be unimportant except with gearing and heavy work, but there is incomplete film lubrication with all machinery on starting, unless some special device is provided to avoid it, and there is always a possibility of incomplete film lubrication during operation if anything goes wrong.

Oiliness appears to be due to adhesion, adsorption or a segregation of some constituent of the lubricant at the boundaries, but it is imperfectly understood and can not be definitely defined. Numerous methods have been proposed for measuring it, but it is still too early to predict what will eventually be the method adopted for routine tests.[12] The difficulty is to measure friction without roughening the rubbing surfaces and thus changing the friction on account of the change in surface. Journal friction machines are unsuitable because the surfaces can not be polished without changing the radius of curvature, and even when this difficulty is avoided by the use of disks[13] or inclined planes, the amount of time spent in polishing is excessive.

There is no longer any doubt, however, that the property of oiliness exists and may be measured under suitable conditions of low speed or high pressure. Low speeds appear to be preferable as less liable to roughen the rubbing surfaces, and Deeley has shown noteworthy differences in oiliness between mineral and fatty oils. The superiority of fatty oils in this respect has long been conceded, and what is of more interest is whether there is

any material difference in oiliness of mineral oils from different crudes. Various investigators are at work and it is to be expected that data will soon be available to help settle this question.

Emulsion Tests and Organic Acidity. There is considerable difference of opinion in regard to the best test to give assurance that an oil will be serviceable for long periods of use in circulating systems as in turbines and automobiles. The chief requirement for a turbine oil is that it must not emulsify in use, or, as it used to be expressed in specifications not many years ago, the oil must separate readily from water. Now this specification is of no value because vague and indefinite, and it may be stated as a fundamental principle that a requirement of a specification cannot be enforced unless expressed as a numerical value which may be obtained by a reproducible method of test.

There are two general classes of emulsion tests. In the first, the oil is agitated by steam and the apparatus required is comparatively simple.[14] It also has the advantage (or disadvantage) that the oil is kept at a high temperature which facilitates the separation of oil from the water. In the other class of tests, mechanical agitation is employed, which permits the use of any temperature and any emulsifying liquid desired.[15]

It is generally conceded that it is necessary that a steam-turbine oil should pass an emulsion test. The difference of opinion arises when it is proposed to use normal caustic-soda solution as an emulsifying agent, or to apply any emulsion test to automobile oils.[16]

There is some justification for the use of an alkali solution in a suitability test, since alkali waters occur in arid regions and steam may be contaminated from boiler compounds. But more important is the question whether an emulsion test with caustic-soda solution is of value as a durability test. Holde[17] devotes a page to tests for "degree of purification," and gives the following test which is similar to, but less accurately defined than, the government caustic test above referred to. "5cc. of 1.5 per cent. sodium hydroxide are shaken with 10 cc. of oil for 2-3 minutes at 80 degrees; the mixture is kept 2-3 hours at 70 degrees. The formation of a skin of soap indicates insufficient purification. The soap is formed from the free naphthenic acids which are neutralized and separated in the presence of the dilute alkali."

The temperatures are given in degrees Centigrade.

It is said as an objection to an emulsion test for automobile oils, that the oil will in any case emulsify after use for a short time, that it does not come into contact with water, and that even if it does it is better to have an emulsion formed than for the water to freeze and stop the oil pump; but this is losing sight of the fact that an emulsion test for automobile oils is not a suitability but a durability test.

In United States Bureau of Standards Technologic Paper 86, previously referred to, it was shown that an emulsion test may be regarded as a sensitive test for organic acidity. As a result of further work it may now be added that oils having a viscosity of over 50 seconds, Saybolt universal at 210 degrees F., should have the demulsibility tested at 180 instead of 130 degrees F., since none of the heavier oils will pass a good emulsion test at the lower temperature. It has also been found that oils of the same organic acidity but of different base may show different demulsibilities, or rates of separation from water, thus apparently indicating that the organic acids present in the different oils are not identical.

If an emulsion test, or the chemical test for organic acidity, is used as a durability test for automobile oils it is necessary to consider the evidence that oils of high organic acidity are not durable in service and tend to form sludge.

It is not certain whether sludge should be regarded as an emulsion or as an oxidation product, since the conditions are favorable for the formation of both. A sludge is unlike an emulsion in that it does not form suddenly, but only after the oil has been subjected to prolonged use. The changes which are known to occur are:

1. Accumulation of metallic particles which act as catalysts to aid oxidation.
2. Accumulation of dust which may be an aid in the formation of emulsions.
3. In the case of internal combustion engines, the accumulation of "carbon" from the cylinders.
4. Oxidation of the oil, accompanied by an increase in acidity, and the formation of oxidation products of a

tarry or asphaltic nature.[18] Of these four causes of sludge formation, the last is the only one which depends upon the lubricant.

Since oils are oxidized when exposed to heat, there is always more or less oxidation during distillation in refining, although steam is introduced to diminish this as much as possible. The more chemically unstable the oil the greater will be the oxidation and increase in acidity. Acidity, then, is an indication of chemical instability, and oils which oxidize and develop acidity in refining may be expected to oxidize and develop acidity in service from the same cause. It is not yet certain just what conditions are necessary to cause the precipitation of oxidation products and other material in the form of sludge.

If in refining, the acidity of the oil is neutralized, thus forming soap, the soap must be thoroughly removed by washing or it will act as a catalyst to accelerate oxidation; while, if the oxidation products are not removed, they themselves will act as catalysts.

It is sometimes claimed that organic acids in oils are present in the original crudes and pass through the refining processes unchanged, but there appear to be no published data on the acidity of crude oils to confirm this, and there is no indication that organic acids occurring in crude oils will be any less active as catalysts than those formed by oxidation.

Since it is possible to neutralize and wash out oxidation products, so that the instability of the oil could not be detected either by the emulsion or the acidity test, it would appear desirable to use an oxidation test. Such a test has been developed and is known as the Waters carbonization test which will be considered later.

Carbon Residue Test. What the automobilist demands of an oil is "mileage" and freedom from carbon deposits. Mileage is, to a large extent, determined by the amount of dilution of the crank-case oil by the heavy ends of the gasoline, and is thus a fuel rather than a lubrication problem. Carbon also depends to some extent upon the tightness of piston rings and quality of fuel, since a lubricant which is reduced in viscosity by dilution with the fuel will more readily find its way into the cylinder.

But to the extent that carbon is determined by quality rather than quantity of the lubricant that reaches the cylinder, a suitable test of the lubricant should indicate the amount of carbon deposits to be expected.

Analyses of the so-called carbon deposits show that they are composed to a considerable extent of asphaltic or tarry oxidation products, and it is believed that what real carbon there is, insoluble in benzol, is due to the cracking of the fuel, the temperature not being high enough at the cylinder walls to crack the lubricant to any great extent. The carbon residue test is distinctly a cracking test, and, if the above analysis of the situation is correct, the carbon residue test is not as applicable to determine the quality of an automobile oil as is the Waters carbonization test.

It is claimed that paraffin-base oils are more often rejected by the carbon residue test and naphthene-base oils by the carbonization test, but this is a question of specification rather than of test method because it depends upon the permissible values adopted as well as upon the ability of oils of different crudes to resist cracking and oxidation.

Waters Carbonization Test. The precipitation test gives the amount of asphaltic matter insoluble in petroleum ether and is used for steam-engine cylinder oils and car oils. Steam-turbine and automobile oils would all show a zero precipitation, but when they are heated they turn dark from the asphaltic matter developed by oxidation, and in the Waters carbonization test the amount of this asphaltic matter is determined.

The oils are heated under standard conditions for a given length of time at a standard temperature, in 150-cc. Erlenmeyer flasks, selected to have a maximum inside diameter of 65 mm. (2-9/16 inches). In the case of used oils the carbonization is the difference in asphaltic matter before and after heating. Other details of the test are given in the following condensed directions.[19]

"Weigh 10 g of oil in each of four flasks and place these in the air bath. Then turn on the heating current and raise the temperature of the bath to 250° C. (482° F.) in 30 minutes, as nearly as possible. Maintain the bath at this temperature for two hours, turn off the current and allow the flasks to cool for about one hour. Remove them, add 50 cc. of petroleum ether to each, cork tightly and gently swirl the contents to dis-

solve the thickened oil. Next day filter off the precipitate in a Gooch crucible in which is a disk of filter paper covered with a thin layer of asbestos. Wash with petroleum ether, dry at 100 degrees C. (212 degrees F.), cool in a dessicator, weigh and calculate the percentage of asphaltic matter on the basis of the original 10 g of oil. This percentage is the carbonization value."

This test has been used in specifications for several years by the government General Supply Committee and the Post Office Department. Not all oils will pass this test, which is as would be expected since it determines chemical instability, which is a difficult thing for refiners to control. Since, however, the greater part of the oxidation is due to the lighter fractions, the carbonization value would be reduced by eliminating the more volatile constituents of the oil—that is, by making narrower cuts—in order to raise the boiling point of the lightest constituent for a given viscosity of the oil as a whole. The narrowness of cut may be determined by a fractional distillation, but a high vacuum is necessary in order to avoid cracking, and on this account the test is much less likely to come into general use than the fractional distillation test for gasoline. It seems preferable to use the Waters test which detects a lack of resistance to oxidation, whatever may be the cause. There is considerable evidence that freedom from sulphur compounds is possibly an even more potent cause of low carbonization than narrowness of cuts.[20] From the point of view of conservation, it is preferable that this should be the case, since the making of narrow cuts would make it difficult to utilize all fractions of the crude oil.

As shown in Bureau of Standards Technologic Paper 86 there is no correlation between carbonization and demulsibility, so that both tests are needed. Fig. 1 shows carbonization plotted against viscosity, the curved line indicating specifications of the General Supply Committee. Apparently, as a general rule, carbonization increases as the viscosity diminishes, which is also shown by the low carbonization values usually found with the very viscous airplane motor oils.[21] On the other hand, the carbon residue values increase as the viscosity increases. Thus the refiner could improve the carbon residue by decreasing the amount of cylinder stock used in blending, but carbonization could be reduced only by decreasing the amount of volatile material; that is, by making a narrower cut.

It has been claimed that the Waters test merely identified the crude and hence was of no value as a quality test. Obviously in the interpretation of tests, conclusions will vary according to what is assumed known and what unknown. A certain well

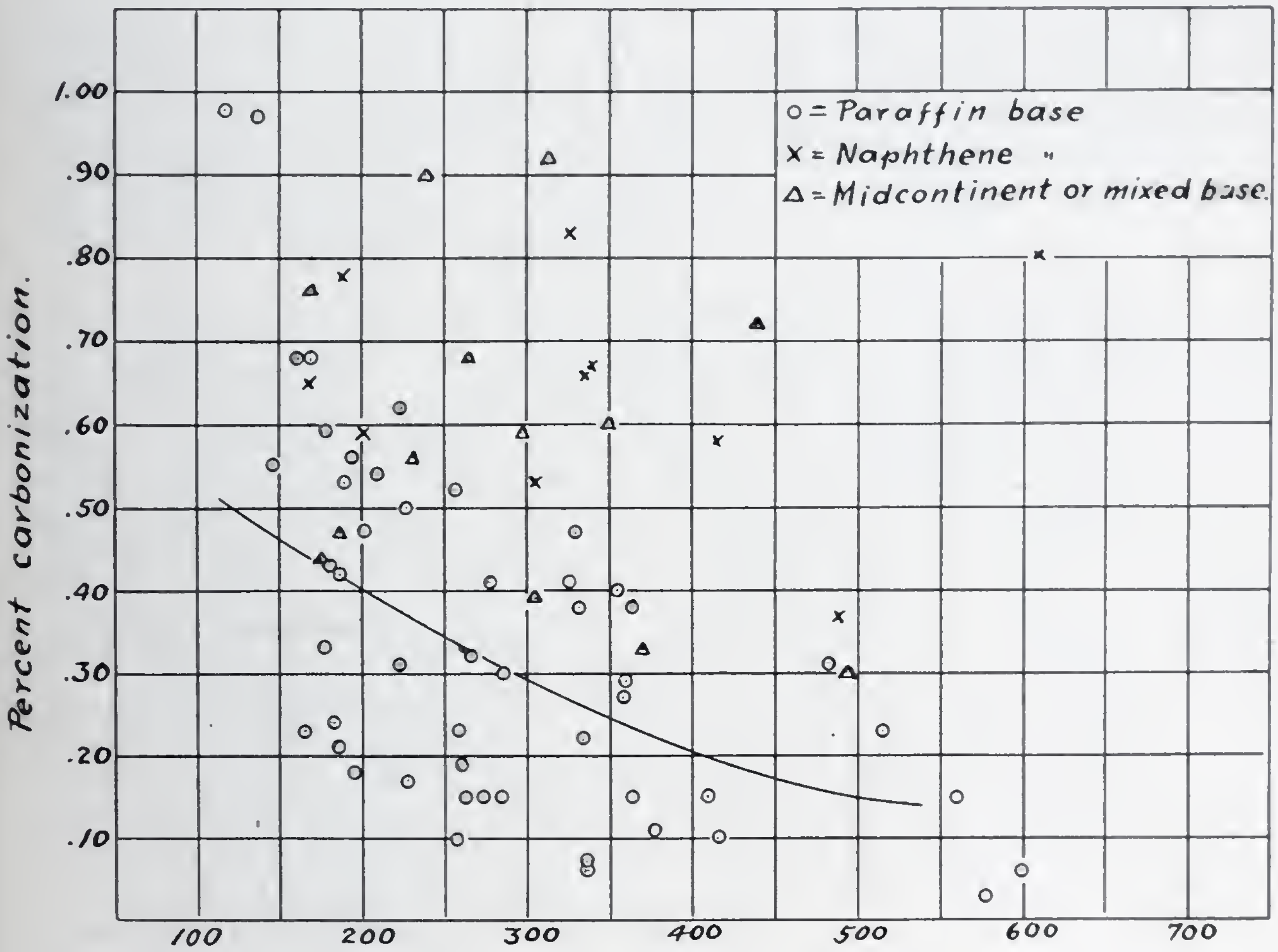

Fig. 1. Carbon and Viscosity.

known, very viscous oil shows a very low carbonization, but high carbon residue, and it has been said by the advocates of this latter test that the Waters test was of no value because it showed a favorable result for this oil which was "just full of carbon." On the other hand, there are those who believe that the Waters test and the oil are both good, and the carbon residue test is meaningless.

To take another example, a certain oil of 230 seconds viscosity, Saybolt universal at 100 degrees F. was submitted to prove that a dark oil did not necessarily have a low demulsibility, and this proved to be the case, the demulsibility being 240. When the demulsibility test was run exactly the same as usual, except that caustic-soda solution was used instead of distilled water, a

value of 71 was obtained which is a fair result for this severe test. The carbon residue was 0.22, there was only a trace of precipitation, and the organic acidity was 0.06 expressed as milligrams of KOH required to neutralize one gram of oil. On the other hand there was a carbonization of 2.59 per cent. Now some would reject this oil on color and some would assume it was a good oil because the carbon residue was low, but my own interpretation of the tests would be that the oil should be regarded with suspicion, not on account of the color but on account of the unusually high carbonization value.

Conclusion. To recapitulate: Of the tests in general use, gravity is necessary to determine absolute viscosity; fire and flash-points are inadequate substitutes for an evaporation test or fractional distillation; and the pour point and viscosity determine suitability but not quality. The less common tests which give promise of determining quality are demulsibility, organic acidity, carbon residue, and carbonization. Demulsibility is the simplest test to make and is more sensitive than the chemical test for organic acidity. The Waters test is preferred to the carbon residue test because it is believed that oils are, in general, exposed to a moderate heat which tends to produce oxidation, rather than to a heat intense and prolonged enough to produce cracking.

Leaving out crank-case dilution, which does not depend upon the quality of the oil, the greatest cause of deterioration of an oil in use is oxidation, and the Waters test appears the best yet proposed to measure the resistance of an oil to oxidation.

DISCUSSION

Mr. J. M. Lessells:* The curve on the board assumes a viscous flow in the liquid. Is there any evidence that the flow in the bearing is not turbulent? If so, it gives the discrepancy which he has pointed out. Furthermore, the viscosity is measured at atmospheric pressure. Should it not be measured at higher pressures, since these are met in practice?

Dr. Winslow H. Herschel: The clearance is so narrow that it is generally conceded that there is no possibility of turbulent flow. The thing that is not taken into account in the theory is the leakage, although this has been taken into account for flat surfaces. The effect of leakage on a journal bearing has never been worked out by the mathematicians. and that is what is wrong in the theory; therefore the curves in practice are not the same as the theory would give you. As to the change of pressure it takes a very, very great change of pressure to affect viscosity. Professor Hersey is here and he can tell you more about that than I can. You do not ordinarily get high enough pressures to change the viscosity very seriously.

Mr. M. D. Hersey:† As to the turbulence; if there were any turbulence, it would be worse at high speeds, and this break occurs at low speed. Then the effect of pressure has to be mentioned and, as Dr. Herschel says, it takes a very high pressure to increase the viscosity very much. But I should think you would have a very high pressure if there were any danger of abrasion in the bearing. Will the gentleman who asked the question make a suggestion as to what he thinks the local pressures might be in such a case?

Mr. J. M. Lessells: I might say the pressure could be infinite where you have a break-down of the bearing itself.

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†Physicist, Pittsburgh Experiment Station, U. S. Bureau of Mines.

Mr. M. D. Hersey: It is a fact that pressure increases the viscosities of such oils as I have worked with—I have tried only five or six oils—it increases them several fold at a pressure of 600 or 700 atmospheres. At a pressure of about 1200 atmospheres (17,000 pounds per square inch) most of the oils, at a temperature of 20 degrees C., get into a condition which might be called solid. They either get plastic or else they get at least twenty times as viscous as at atmospheric pressure and possibly quite solid. To heat them up to 100 degrees C. under pressure, shows the same effect but, of course, not so bad; and I have solidified a number of oils at a temperature of 100 degrees C. by squeezing them to about 3000 atmosperes. I don't suppose there is very much danger of this effect in a bearing where the oil is a great deal hotter than 1000 degrees C., so it still remains a speculation just what influence these figures have.

Mr. J. E. Babb:* There is no question but that we know very little about oils. I do not think any one knows this any better than the man who attempts to make a grease out of the different oils, or extracts the oil from a lubricating grease and determines the gravity and the viscosity and then tries to find out what two oils are compounded in order to make the grease. Sometimes he may try two or three times and succeed and other times he may try for two or three weeks before he gets the proper combination of oils which will make the right grease or duplicate an outside grease.

There is no question that viscosity is the only test we have to-day that is of any value as a guide to lubrication; but what is the use of determining viscosity when the user knows little or nothing about bearings and has no regard for the pressures, speed, and variations of temperature, and the producer does not always have a knowledge of where the oil is to be applied. I find the greatest difficulty in lubrication is the ignorance of the user, rather than that of the producer. The producers can not be expected to know every bearing type that is in use in the universe. The only value the producer attaches to viscosity, in my experi-

*Superintendent of Grease Plant and Director of Chemical Laboratory, Waverly Oil Co., Pittsburgh.

ence, is this; that he tries an oil of light viscosity and if that does not work he tries something else and after two or three attempts he may hit it. First of all, oils are made to work, and when found to be satisfactory their viscosity is determined. At least in the beginning this had to be done before the relation of viscosity to a particular type of bearing or machine could be known. This is especially true in the use of lubricating grease in rolling-mill lubrication and unless you are familiar with the machinery and have what is known as the grease sense it is difficult to select a grease that will lubricate mill bearings. We have no means whereby we can employ a test which will function in the same way viscosity functions with oil.

In regard to overrefining oils, or perhaps overtreating with acid or passing through fullers too many times, I think our friend Dr. Acheson made the statement that by overrefining we take out the colloid and depreciate the lubricating value of the oil. Perhaps it takes out too much organic acidity, which is something we have yet to define. I have for some time endeavored to find out more about so called organic acidity and we seem to be unable even to measure it—at least I know very little about it.

We have the case of oxidation of oils, not in the cylinder but in the container at normal temperatures when oils of high viscosity and gravity are compounded to form a grease with a calcium soap made from tallow, this grease when kept for a few months in a closed container develops a very viscous film on the top. What causes this I do not know. It may be organic acidity; it may be that the iron in the container acts as a catalyzer and accelerates the oxidation. I am sure the soap has nothing to do with it. As not all oils behave in this way it may be interesting to expose the above oils in thin film on metal plates to the air for some time and look for oxidation effects, or we may blow air through the oil at normal temperatures in contact with iron which may give quicker results. We expect to make the above experiments.

Speaking of the durability of oil, the question arises as to where oil disappears to when we apply it to a bearing. If you have too light an oil for a heavy bearing we know we have loss through leakage. That can be remedied. Furthermore, the durability of an oil is its ability to stay put and possess a low leakage

loss. This seems to be a function of viscosity, but you attach a different significance to the term durability. You can make an oil disappear only through leakage at normal temperatures. In fact, it is simply a matter of leakage. You will have to define that durability test a little more clearly.

I would like to have Dr. Herschel give us his opinion about the problem of oxidation.

Dr. Winslow H. Herschel: Dr. Waters has shown very clearly that various metals have a powerful catalyzing action in hastening oxidation of oils.

I cannot accept Mr. Babb's definition of durability. It has nothing to do with disappearing. By durability, I mean the deterioration of the oil, mainly by oxidation. On the other hand, the question of leakage is a mere question of viscosity. It is a question of the suitability of the oil for the particular bearing. The question of durability is a question of the chemical stability of the oil to resist disintegration or any chemical change of that nature, and it has nothing to do with its remaining on the bearing.

Mr. J. E. Babb: One more question on durability. If we can have a perfectly tight bearing, if we can prohibit all loss through leakage, if we can use a submerged type of bearing for any ordinary use which will not raise the temperature abnormally, how long will a low viscosity oil last and how long a high viscosity oil?

Dr. Winslow H. Herschel: The question of how long the oil will last if it does not escape by leaking, depends on the use to which it is put. Take the two most common classes—steam-turbine and automobile oils. In the turbine you expect that oil to last a long time. I know of an oil that lasted five years without draining the reservoir. That is perhaps long enough. In an automobile the conditions of use are more severe, but on the other hand you do not expect it to last so long, so that one case is not so very different from the other.

Now it is known that almost any use of an oil will increase its acidity. Ordinarily it will increase in viscosity. In a steam

turbine where there is no crank-case dilution, there is an increase in viscosity showing that oxidation is taking place. The ultimate result, if the oxidation progresses far enough, is the formation of an oxidized product of an asphaltic nature. Asphalt is nothing but an oxidized oil. But in reality it may proceed further than this. If the oxidation continues further you get a material which is very difficult to distinguish from carbon because it is insoluble in practically everything, while asphalt, though insoluble in gasoline is soluble in benzol.

Mr. J. E. Babb: If we use a submerged type or closed type of bearing and there is no volatilization, there can be no loss; so we cannot define the durability of an oil without taking into consideration the leakage losses. It is true that oils undergo oxidation on coming in contact with various metals, and the refiner, against whom I hold some brief, should know more about this. As I happen to be manufacturing grease I have more trouble in compounding oil to make grease than the man who runs an automobile.

Dr. Winslow H. Herschel: Without saying that there is any such thing as an oil that will last indefinitely, I do say that there is a difference between oils—there is a better and a worse, and to that extent the oil which is worse is responsible. Of course, if you supply a catalyzer, you are going to have a more rapid deterioration of the oil when it is present than when it is not present; but if used under identical conditions one oil will gum faster than another. The gumming to which Mr. Babb refers is what I call lack of durability. Now I have considerable sympathy with Mr. Babb because he says he has troubles of his own, and I have an idea that a lot of his troubles are due to the fact that he tries to identify an oil by such tests as gravity and then he wonders why an oil with a given gravity will make a good grease and another oil with identically the same gravity somehow seems to have entirely different properties and will not make a good grease. That is exactly what I should expect.

Mr. Max Hecht:* The user of lubricants and the oil technologist have, in recent years, emphasized the need of a greater

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knowledge of lubricating oils, and it is gratifying that common ground is being reached on this subject. A greater use of oil tests is being made to-day by both producer and consumer; and, in addition, service tests supplement the laboratory tests so that the operator is assured that the lubricant answers his requirements.

Speaking principally concerning the modern developments in steam-turbine design and practice, such machines operate at higher steam temperatures and pressures, which in addition to concentration of large elements in single units complicates the problem of lubrication in that there is found heavier bearing pressure. Lubrication is of the forced-feed type, the oil being in service continuously with only such changes as can be accomplished by clarification, either of a whole or of a part of the volume. Successful operation of equipment of this type makes the lubricant an item of importance.

For a period of over a year, careful supervision has been exercised on our turbine oil deliveries. The tests as outlined in the paper presented this evening have been made on such deliveries excepting that the distillation and Waters tests have been omitted. While no specifications are used (prior service of the oil indicated a satisfactory lubricant) it has been noted that a remarkably close check on the quality of separate deliveries has been maintained by the producer.

Values as noted below have been consistently found:

Demulsibility, 1200 cc. per hour.

Neutralization value, 0.02 milligram of KOH per gram of oil.

Viscosity at 100 degrees F., 145 seconds (Saybolt).

We have observed that in some of our turbines changes occur when the oil is placed in service. Within a few hours, there are found values for demulsibility ranging from 200 to 300 cc. per hour; neutralization values within a few days requiring 0.10 milligram of KOH to neutralize one gram of oil, and slowly rising values for viscosity. When the oil carries approximately 0.5 of water the rise in the neutralization value is somewhat rapid. However, we do not find a value lower than 100 cc. for demulsibility with an oil the neutralization value of which is approximately 1.5 milligram of KOH.

Some oils in service at least 10 years, "sweetened" periodically, while they showed a neutralization value of 0.60 milligram of KOH, and also showed a demulsibility of 100 cc. All of the oils referred to are Pennsylvania crude, refined without acid treatment.

Oil technologists indicate that an oil may sludge either due to emulsion or oxidation produced by metallic particles (acting as catalysts), dust, water, heat, air, and electrolytic action.

It may be stated that any or all of the above factors may be present in a lubricating system.

What then, is the danger point, to warn the operator when to reject an oil from the lubrication system? He cannot afford to wait until sludge accumulates restricting oil flow, nor can he afford to have seized bearings.

Can the oil technologist tell us a readily usable test showing when to reject an oil in service? Obviously, from our observations the demulsibility value does not indicate the danger point. Is the neutralization value an index? If so, what is the maximum value permissible? What is known of the mechanism of electrolytic action on a lubricating oil?

Mr. C. J. Rodman:* I would like to ask Dr. Herschel if there is any general relation between the lubricating values of an oil and the degree of saturation of an oil. Much importance has been ascribed to the value of small additions of free fatty acids and especially to the oils of high viscosity containing quite appreciable amounts of unsaturated constituents.

I would also like to ask what durability test Dr. Herschel thinks is the best one for most nearly meeting service durability. I have reference, of course, to chemical durability tests. We have so many tests which in a sense measure the probability of oxidation of an oil to make a sludge of some kind. It would be interesting to know if only the unsaturated constituents of an oil form sludge. Such tests as the Babcock absorption, Michie air oxidation at elevated temperatures, the "Formolit" condensation, the halogen substitution methods and many others have been tried in

*Chemist, Research Laboratory, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

our laboratories and I am at a loss to know just what value to attribute to any of these tests.

Dr. Winslow H. Herschel: Wells and Southcombe, about 1920, brought out the idea that you could increase oiliness of a lubricant by adding small percentages of fatty acids. That idea has been seized on with avidity by the oil refiner as a probable reason why it would be beneficial not to overrefine the oils but to leave in them a small proportion of organic acidity, on the supposition that the organic acids would have the same effect in reducing the coefficient of friction as produced by the fatty acids which were added by Wells and Southcombe. Now that has not been entirely demonstrated, as yet. It may be so. If it is so, we have a case where we have to compromise between too great an amount of unsaturated compounds which will cause gumming, and too small an amount of unsaturated compounds which will too greatly decrease the oiliness or increase the coefficient of friction.

Dunstan and Thole in England say that it is up to the refiner to remove the more unstable of the unsaturated compounds because they cause gumming, while retaining in the oil the more stable of the unsaturated compounds on account of their beneficial effect in reducing the coefficient of friction. I see Dr. Faragher is here, and I know he has been working along these lines. I do not know just how much he will care to divulge of the results of his investigation but I would like to ask him whether it is feasible for refiners to distinguish between the more stable and the less stable of the unsaturated compounds and follow the advice of Dunstan and Thole.

Dr. W. F. Faragher:* It is impossible to say what classes of compounds are so easily oxidized under the conditions of service met by turbine oils and by engine oils used in continuous oiling systems, that certain lots of lubricants of these classes give trouble within a relatively short time. Our knowledge of the chemistry of the substances present in the higher-boiling fractions of petroleum is so incomplete that it is impossible to state in the case of the products other than gasoline and burning oil from most crude oils, even the series of hydrocarbons which are present. Very

*Mellon Institute of Industrial Research, Pittsburgh.

little is known, also, about the compounds of sulphur, oxygen, and nitrogen existing in these higher-boiling fractions. This lack of accurate, detailed chemical information about the constituents of lubricating oils makes it necessary to attack many of the problems of their preparation and use by wholly empirical methods. Practical oil men have been loath to make the large expenditures which would be required to procure this chemical knowledge, since they have not foreseen the financial benefits which they would derive from it. Certainly all petroleum chemists are convinced that the expenditure would be a wise one. It is to be hoped that the co-operation of our government and educational labratories can be enlisted in a program of research on these fundamental chemical problems of the petroleum industry, and that practical oil men will support the work co-operatively.

Various statements have been made and repeated in the literature, concerning the substances which cause sludging and emulsification in turbine oils. Certain (unnamed) unsaturated hydrocarbons and sulphur compounds have been said to cause these troubles by undergoing oxidation. It is altogether probable that oxidation is the fundamental process involved, as Dr. Herschel has said. I know of no data, however, which give real information about the original substances or the products of the oxidation. I cannot, therefore, answer Dr. Herschel's question regarding the identity of the substances which cause oils to behave differently under the same conditions of service. We all know, of course, that the differences exist, and all hope that we may soon have reliable durability tests for predicting the behavior of a lubricant under service conditions.

I agree in the main part with Dr. Herschel's statement, that we need a number of durability tests, but I disagree with him when he says that we should at the present time apply those which he has described. Our knowledge of the relationship between the changes effected in the oils by the conditions of test and those effected in the same oils by the conditions of service, is too fragmentary now to enable us to apply the tests intelligently. The tests, as tests, may be satisfactory, but even this opinion must await the establishment of the relationships mentioned above before it can be accepted finally. The tests, as tests, are of little utility; the important thing is a decision on the limiting values of

the factors which they measure, which should approve or condemn a given oil. We know too little now to attempt to apply most of these durability tests with exacting limiting values.

Wells and Southcombe have never said, so far as I know, that the acids which are developed in lubricating oils as the result of oxidation processes, are beneficial. In their patents and published papers, they specify the use of fatty acids, such as those prepared from rape, olive, or cocoanut oil. No other investigators have reported favorably or unfavorably on these petroleum acids, in so far as their function as lubricants is concerned. Tests which we have made at the Mellon Institute of Industrial Research have shown that the organic acids present in samples of commercial lubricating oils (from California crude oil) used by us, do not lower the coefficient of friction as do the fatty acids of high molecular weight. In making these tests, a Kingsbury oil tester was employed. Low speed and high bearing pressures were used in order that the bearing should operate without complete film lubrication.

Dr. Winslow H. Herschel: I think there is one point there that should be pointed out in government specifications—the value of 300 demulsibility in new oil. I did not understand Mr. Hecht to say that he would accept a new oil with a demulsibility of 100—the 100 was after use. But we were not talking of specifications to-night, but of methods of testing. As to what values should be put on these different methods of testing to get a passing grade, that is another matter.

Mr. Max Hecht: I agree with Dr. Herschel in the discussion about tests, but even if the material is bought on specifications, can we then tell that the specification is met? From an operating standpoint it is absolutely essential that there be some measure of serviceability readily available to indicate probable failure of the oil.

Dr. Winslow H. Herschel: I am surprised at the test which showed that when the demulsibility got down to 100 it did not go lower. Much lower values for demulsibilities of

used turbine oils are reported in Technologic paper 86 of the Bureau of Standards. The demulsibility test is regarded as a very sensitive method of measuring organic acidity when it is present in such small amounts that it can not be measured by chemical means. I notice Mr. Hecht measured it down to 0.02. Most chemists would throw up their hands if you asked them to measure organic acidity to such a degree of accuracy. They would say it was a mere trace or could not be detected.

Mr. Max Hecht: We consider 0.10 the checking limit on neutralization value. However, we have been able to check within 0.01 consistently in our own laboratory. We are, of course, dealing with 20 grams of oil instead of 10.

Dr. Winslow H. Herschel: If the demulsibility would enable you to select a new oil, and even if it does stop going down when it reaches 100—which I should like to see confirmed, as it is not in accord with my experience in the use of turbine oils—by the time the demulsibility has got down to 100 the organic acidity has gotten high enough so that anybody can measure it, and the problem for an operating engineer as I see it is to set a value of organic acidity, carbon residuum, or carbonization at which the oil should be rejected as being unfit for further use.

Mr. F. K. Howell:* As a matter of general interest, I would like to ask how, from your experience, centrifugal separation, as against ordinary filtration, affects the durability of a good average turbine oil.

Mr. J. E. Babb: I would like to say a word about organic acidity. It is very difficult to make the determination as described by Mr. Hecht. If the determination can be made at all it can best be done by adding an excess of alkali to the oil, separating the oil (and soap if any), and determining the excess of alkali over that which has combined with any organic acids present in the oil.

*Superintendent, Compressing Stations, Philadelphia Co., Pittsburgh.

Dr. Winslow H. Herschel: That is a little different interpretation of the word durability. By durability I was referring to the inherent properties of the oil. This is a mere question of how long the oil would last in use when kept in good condition by different continuous processes of reclaiming. I have not had sufficient experience with different methods of continuous reclamation to answer that question. It is a rather broad question, as to whether the centrifugal method of removing sludge would make the oil last longer.

Mr. Max Hecht: I should like to refer you to the 1922 *Proceedings* of the National Electric Light Association, Report of Prime Movers Committee, which has gone into that subject somewhat extensively.

Mr. C. M. White:* I should like to ask a question that does not bear directly on tests, but would be of great interest to myself and others of the operating men present. Has the speaker prepared a chart or figures showing the relation of viscosity to bearing pressure or what variation between viscosities at different temperatures should be required for various bearing pressures?

Dr. Winslow H. Herscel: The curve which I drew on the blackboard is very useful. That point of minimum friction is a point that can be figured out mathematically. I gave the equation for it in the *Journal of the Society of Automotive Engineers* last January. It was pointed out by Dr. Wilson that what we need for operating conditions is a sufficiently high factor of safety above that point of minimum friction. Actually you can sometimes run down to that, but sometimes you do not get as far as that. Bearing pressure, viscosity, and speed all come into calculation of that point.

Mr. C. M. White: You have not worked out an equation on bearing pressure?

*Superintendent, The Monongahela Connecting Railroad Co., Pittsburgh.

DR. WINSLOW H. HERSCHEL: You can not pin it entirely on that factor. The higher the speed the better the bearing oil is drawn into the place of nearest clearence between the journal and the bearing, and, therefore, the higher pressure it will stand. You cannot put your mind entirely on one factor and say that the pressure will determine what the viscosity of the oil should be, nor can you say that the speed alone will determine the viscosity that should be used for a given pressure.

MR. C. M. WHITE: One other question. Is it understood that the acidity in the oils is lower in a Pennsylvania crude base than in an acid-treated asphalt base? From an operating standpoint it is much better to use Pennsylvania crude than an asphalt base which has been acid treated.

DR. WINSLOW H. HERSCHEL: I think I made the statement, earlier in the evening, that government specifications do not discriminate against either crude because we are not convinced that one has shown a paramount advantage over the other. It is not necessary to know the base of an oil in order to test acidity. When we have tried to get oil of a definite crude, the refiners have told us that they themselves did not know what base it was as the oil got mixed in the pipe-line. I do not believe the base of an oil can be identified with any great degree of certainty. It might have been, years ago, when the oil was either a naphtha base or a pure paraffin base. Now we have a blend of naphtha and paraffin oil and I do not believe any one has published any method for determining 5 or 10 per cent. of one oil mixed with oil of another base; so I do not see that you are going to get very far by assuming that one base is better than another. You must have tests which you can apply without knowing what base the oil is.

MR. M. D. HERSEY: I think I know the answer to the question about bearing pressures. If you double the bearing pressure you should use twice as much viscosity, provided you have a bearing of the same type. This conclusion is in agreement with Dr. Herschel's diagram. If you have a bearing that is satisfactory and the *only* change you make is to increase the bearing

pressure, then you should increase the viscosity in proportion—this means the true viscosity in the film.

Dr. W. F. Faragher: Leakage of oil from the bearing, and other factors at variance with the assumptions employed in establishing the relationships shown in Dr. Herschel's curve, would make impossible in this case the use of Dr. Herschel's line of reasoning.

Mr. M. D. Hersey: Why do you need to assume that there is no leakage and that the figures, therefore, are not reliable? You can arrive at substantially similar results by another method (the dimensional theory), which does not assume that the leakage is non-existent.

Dr. Winslow H. Herschel: I was referring not to the fact that the coefficient of friction is a function of this particular ratio to which Professor Hersey is referring, but to the exact shape of the curve. I said the shape of the curve is not exactly the same as they figure out, presumably on account of these end leakages. But, as Professor Hersey says, the mere fact that the coefficient of friction is a function of this ratio, he has figured out quite independently.

Mr. L. W. Heller:* Mr. White asks how the friction due to pressure is affected by temperature.

For a period of six months we have conducted a test on a 15,000-kilowatt turbo-generator, to note the effect of friction bearing loss due to temperature. The temperature of the oil was varied by reducing the amount of cooling water through the oil coolers. The test, of course, is relative, making use of the thermometer set in the various oil lines. It was found impracticable to set up absolute test conditions, which would require an effort to get the temperature of the oil film. The results of the test indicate that a wide variation in friction bearing loss can be attained by the control of the oil temperature.

*General Superintendent of Power Stations, Duquesne Light Co, Pittsburgh.

From an operating standpoint, the vital thing is assurance that the oil will not function improperly. It is, therefore, evident that viscosity and friction bearing loss are of less importance than durability of the oil.

As stated this evening, organic acidity is one factor on which considerable emphasis should be placed, as it is an index of the probable deterioration of the oil.

Operation of large turbo-generators, in recent times, necessitates continuous service from the unit for from six to eight weeks. This period is extended at times to even a year or two. No time can be spared to take the machine out of service and cleanse the oil.

The oil producers and the oil technologist must bend every effort, therefore, to developing a lubricant to meet the requirements of continuous service without deterioration.

Dr. Winslow H. Herschel: It should be remembered that it is possible to reduce the friction greatly if you are willing to sacrifice the factor of safety. If you heat up your oil and thus reduce the viscosity you will get a lower friction, but you will come down nearer to the viscosity of minimum friction and cut down your factor of safety. That is the great danger in service tests. Very often an oil will be substituted for another in the attempt to show that it is a better oil, when all that is really done is to substitute an oil of a lighter viscosity and get a lower friction at the expense of a lower factor of safety.

Mr. J. R. Buchanan:* The selection of the proper oil for use with steam turbines should be given serious consideration by the users. The oil suitable for use for lubricating turbine journals must be pure mineral, hydrocarbon oil free from tarry, slimy or saponifiable matter; acid, soaps or thickeners; water, dirt, grit or other suspended matter.

The specific gravity should be between 0.860 and 0.880 at 60 degrees F.

The flash-point, open-cup tester, must not be below 334 degrees F.

*Local Engineer, General Electric Co., Pittsburgh.

The viscosity as determined at 40 degrees C. by the Saybolt viscosimeter should not be greater than 228 seconds, except when turbines drive reduction gears, when oil having a viscosity of 300 seconds is recommended. Experience with existing lubricating systems has shown this viscosity to be most satisfactory. Several factors influencing the performance of lubricating oil may be considered.

Foaming. Oil foaming is caused by intimately mixing air with the oil, which may be due to air leaks in the pump suction line, trapping air in the oil reservoir when adding a large volume of new oil, and allowing the oil returns to drop upon the surface of the oil in the reservoir and cause severe agitation with air. Oil foam will fill up the air spaces of the oil reservoir and bearing, and if in excessive quantities will creep out causing an oil loss. Oil foaming can sometimes be rectified by circulating the oil at a higher temperature, which will thin the oil and heat the air, causing the bubbles to break up quickly.

Acidity. Acids found in a petroleum oil may be divided into two kinds—mineral acids which are soluble in water, and petroleum acids which are insoluble in water.

Mineral acids attack metals, causing pitting and corrosion. These acids when present, indicate that proper care has not been used in the manufacture as such acids are rarely found in high-grade oils used in turbine circulating systems.

Petroleum acids do not attack bearing metals. In new oil, their percentage is small, probably not more than one-half of one per cent.

After oil has been in service for a considerable period of time, petroleum acids may be formed. It has been found that the oxidation of the oil increases the percentage of acidity of the oil. At the saturation point, the oil can no longer hold all the acids in solution and precipitation takes place. The percentage of acidity which determines the saturation point of the oil is variable, in that used oils will hold larger percentages of petroleum acids in solution than new oils. Precipitate is sometimes formed in used oil by the oxidation of hydrocarbons without the formation of petroleum acids. This precipitate does not settle out easily.

Sludge. The precipitates which form in used oil from oxidation and acidity are commonly known as sludge. Heat, water,

and insoluble impurities will increase the rate at which oxidation and acidity will take place.

Emulsions. It is quite difficult to prevent water leakage into the oil system from packing glands. Water will enter the lubrication system when the turbine is shut down, due to condensation on the inside of the bearing housing when cool. It may enter the system through small leaks in the oil cooler and in some cases, which however are exceedingly remote, through cracks in the water-cooled bearings. Steam condensation when formed, entering the lubricating system especially when feed-water has been chemically treated, is very objectionable.

Emulsions will form when water is present in a turbine circulation system. An emulsion is an intimate mechanical mixture of liquids, insoluble in one another where one is suspended in the other in the form of minute globules. A pure water-and-oil emulsion will readily separate when it is allowed to rest. Forcing finely divided insoluble substances into a mixture with the oil and water, forms an emulsion of a permanent nature; therefore, an increase in acidity which forms a precipitate in the oil and any foreign impure substance forms a permanent emulsion and assists in the more rapid formation of an ordinary emulsion.

The elimination of emulsions and sludge from a lubricating system is very necessary. These impurities will precipitate in the oil reservoir, on the strainer filter, and in the oil pipes, and prevent the efficient operation of the lubricating system.

To summarize; the proper turbine oil should be capable of maintaining a lubricating film on all bearing surfaces under all conditions of operation, and conducting heat away from the bearings. To accomplish this, experience has shown that a continuous filtration system is of very material economic benefit in preserving the proper lubricating qualities of the oil.

Mr. Winslow H. Herschel: Mr. Lessells' question in regard to the necessity of measuring viscosity under pressure may be answered by reference to the figure drawn on the blackboard. As this figure is not given in the paper, a brief description may be helpful. The ordinate is the coefficient of friction of a journal bearing, and the abscissa, which may be called S for convenience, is the product of two terms, of which the first is the product of

viscosity and speed divided by the pressure, and the second is the square of the ratio of journal diameter to clearance.

It is difficult to see under what circumstances the difference between two oils in the change of viscosity with pressure, could be very important, but if desired, viscosity under pressure may be obtained by the rolling ball viscosimeter of Flowers or by the methods described by Hyde and others.[22]

In the diagram referred to, starting with the coefficient of friction of rest, the friction drops very suddenly until a minimum value is reached, when S equals S', and, as S is further increased the friction slowly increases. Similar theoretical curves are given by Hersey.[23] Now for values of S greater than S' the pressure in the oil film is not great enough to change the viscosity materially. For values of S lower than S' Sommerfeld's equations show that the pressure in the oil film increases, reaching infinity when S equals zero. The significance of this result is greatly reduced by the following considerations.

1. At the lowest value of S at which continuous operation has ever been attained, the maximum pressure in the oil film is only about five times the nominal bearing pressure as usually obtained by dividing the load by the projected area.

2. Since the increase in friction, with decrease of S below the value of S', is much more rapid than calculated by Sommerfeld, it is evident that his equations do not apply to these conditions, probably because there is incomplete film lubrication, and hence the equation for pressure in the oil film would also be inapplicable. It is of course realized that none of Sommerfeld's equations is exact, because neither he nor any other mathematician has succeeded in taking the leakage from a journal bearing into account; but, by "inapplicable," I mean a much wider divergence between theory and experiment than is found with values of S above S'.

3. It is generally recognized, as indicated by tests of cutting oils, that, when there is incomplete film lubrication, then oiliness, rather than viscosity, becomes the property of major importance, in contrast to conditions of complete film lubrication where oiliness has practically no effect, and viscosity is the only property of the lubricant upon which friction depends.

It does not seem possible at this time to fulfill satisfactorily Mr. Hecht's requirement for an infallible test to determine when an operating engineer should discard the oil from a turbine.

It seems desirable to use some continuous filtration system, as suggested by Mr. Buchanan, and further work is evidently needed in regard to the saturation point to which he refers.

I can give Mr. Hecht little hope that organic acidity (neutralization value) will prove a satisfactory index to when to reject an oil in service, present indications being that the carbonization test, which shows the amount of oxidation products which have been formed, is the preferable test; for, apart from extraneous material such as dust and metallic particles for which the lubricant is not responsible, the precipitate or sludge must be composed of oxidation products.

My colleague, Dr. Waters, has recently examined a turbine oil said to have been nine years in use, together with a representative sample of the new oil, and the results may be of interest. No sulphuric acid could be detected in either the new or used oil.

Test	New oil	Used oil
Acidity, mg. KOH per g.	0.05	0.61
Demulsibility at 130 degrees F., cc. per hr.	120	26
Carbon residue, per cent	0.36	0.60
Carbonization, per cent	0.12	1.04
Sulphur, per cent	0.11	0.13

It will be noted that many oils are higher in acidity when new than this oil was after nine years of use. It is possible, however, that, although the value of acidity has little significance because the identity of the acid is unknown, the rate of change of acidity with time may be more significant of an approach to the saturation point where sludge is formed. It will be observed that with the exception of acidity, the carbonization shows the highest percentage of change.

Mr. Rodman raises the question of the relative value of tests for unsaturated compounds and oxidation tests. While it is of course of interest to investigate causes of oxidation, it would seem far simpler to make one test to determine the amount of oxidation, whether due to unsaturated compounds, aromatics or

whatever cause, rather than to make separate tests for each possible cause of oxidation. If, for example, the oxidation were largely due to sulphur, tests for unsaturated constituents alone would be misleading in regard to the chemical stability of the oil.

As regards the Michie test, it apparently measures the same properties of the oil as does the Waters test, but it is more complicated in apparatus and operation, and the 45 hours required is an unreasonable length of time. The standard temperature for the Waters carbonization test for lubricating oils is 250 degrees C. (482 F.) which might cause trouble when applied to the more volatile transformer oils, on account of spontaneous ignition of vapor in the flasks. Doubtless a suitable lower temperature could be found for transformer oils, low enough to avoid this possible difficulty of "flashing" and yet high enough to yield, within a convenient period of heating, sufficient amounts of asphalt to give reliable comparative data.

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BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Parlor "D", Tuesday, December 12th, at 4:40 P. M. President Henry D. James presiding, Messrs. Crabtree, Hildner, Hunter, Khuen, Hobbs, Hawley and the Secretary being present.

The Minutes of the last meeting held Nov. 21st, were approved without reading.

Applications for membership received from the following gentlemen, having been previously published to the Society in accordance with the action of the Board, were elected to membership.

MEMBERS

Gallinger, Walter N.
Ingram, Herschel Anthony
Mantle, Gregory Douglas
Miller, Harry R.

ASSOCIATE MEMBERS

Bradford, Herbert H.
Kirkpatrick, George Myers

Applications were received from the following gentlemen and ordered published to the Society in the grades recommended by the membership committee.

ASSOCIATES

Dalzell, James Willis
Parmelee, Earle Linsley

MEMBERS

Chappell, Thomas V.
Cooper, Howell C. (A. S. M. E.)

ASSOCIATE MEMBER

Thomson, Joseph Carl

The report of the Secretary, showing the financial condition of the Society at the close of business November 30th, having been audited by the Finance Committee, was approved.

COMMITTEE REPORTS

The Secretary reported verbally on behalf of the Entertainment Committee stating that final arrangements were being made for the Annual Banquet, January 22nd. Two speakers have been secured and it is hoped to have the third by the end of this week.

Mr. Fohl, Chairman of the House Committee, reported an evening attendance of 169 for the month of November.

In addition to the regular report, the Secretary reported verbally stating that the Committee is considering the possibility of a bridge tournament in the spring ending with an evening of bridge at which the ladies would be invited. Mr. Fohl did not wish to take any definite action until the Board had discussed the matter especially with regard to card playing in the rooms of the Society, as it was felt this might establish a precedent.

After a general discussion, it was moved and carried that the Board issue a statement permitting card playing in the Rooms of the Society with absolute restrictions against any form of gambling or poker and further that the Secretary announce this to the entire membership.

In accordance with Article 5, Section 5 of the By Laws, it was moved and carried that the nominations as published to the Society be finally approved and that letter ballots be mailed to the entire membership in accordance with the By Laws.

On motion the meeting adjourned at 5:20 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, December 5th, at 8:15 P. M., Mr. K. T. Stearns presiding in the absence of the Chairman, 58 members and visitors being present.

The Minutes of the last meeting held October 10th, were read and approved.

There being no further business before the Section, the paper of the evening on "The Modern Industrial Gear" was presented by Messrs. W. H. Phillips, Mgr. Engineering Dept. and L. F. Burnham, Mechanical Engineer, R. D. Nuttall Co.

The ensuing discussion was participated in by: G. E. Flanagan, Mech. Engr., Heyl & Patterson, Inc.; W. M. Austin, Elec. Engr., Westinghouse Elec. & Mfg. Co.; J. R. Cline, Practice Man, Universal Portland Cement Co., Universal, Pa.; K. T. Stearns, Engr., West Penn Power Co.; F. F. Espenschied, Engr., City Transportation Repr., Commercial Truck Co., and the authors.

On motion, duly seconded and carried, a vote of thanks was extended to the authors for their very interesting paper.

The meeting adjourned at 9:45 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 409th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, December 12th at 8:03 P. M., President H. D. James presiding, 73 members and visitors being present.

The Minutes of the last meeting held November 21st, were read and approved.

The Board of Direction reported the election of four applicants to the grade of Member, two to the grade of Associate Member and two to the grade of Associate, and the receipt of three applications for membership. Also the receipt of four resignations.

No further business coming before the Society, the paper of the evening on "Developments in Methods and Apparatus for Testing and Balancing" was presented by Mr. T. Y. Olsen, V. P. & Treas. Tinius Olsen Testing Machine Co. Philadelphia, Pa.

The ensuing discussion was participated in by: G. L. Jones; H. D. James, Mgr., Control Engineering Dept., Westinghouse Elec. & Mfg. Co.; R. L. Templin, Chf. Engr. of Tests, Aluminum Co. of America, New Kensington, Pa.; W. J. Merten, Metallurgical Engr., Westinghouse Elec. & Mfg., Co.; T. D. Lynch, Research Engr., Westinghouse Elec. & Mfg. Co.; J. C. Hobbs, Mgr., Allegheny County Steam Heating Co.; R. Soderberg, Westinghouse Elec. & Mfg. Co.; and the author.

On motion duly seconded and carried, a vote of thanks was extended to Mr. Olsen for his very interesting paper.

The meeting adjourned at 9:57 P. M.

K. F. TRESCHOW, *Secretary.*

GENERAL INDEX

NECROLOGY

Allen, Hugh P.

Barbour, George H.

Cade, Charles W.

Cunningham, James S.

Gudmundsson, Gisli

Kimball, Frank I.

Lauman, August H. Jr.

McGinley, John

Purdy, William F.

Schellenberg, Francis

Whittaker, Lee

Wilkins, William G.

Wood, E. F.

George H. Barbour

Born March 3rd, 1867.
Died Pittsburgh, Pa. April 19, 1921.
Director 1913, 1917, 1918 and 1919.
Joined Society, April 1888.

George Hurlbut Barbour was born March 3, 1867, in old Allegheny, now the North Side of Pittsburgh, Pennsylvania. He was the son of Joseph Barbour, Scotch Irish, a native of Londonderry, Ireland, and Anjanette Hurlbut Barbour, born in Allegheny, but of old New England stock. Mr. Barbour was educated in the Public Schools of Allegheny, had a year or two of college preparatory and then entered the Western University of Pennsylvania. now the University of Pittsburgh. He graduated from the University as a civil engineer in 1887, one of class of six.

He was first employed by the Shiffler Bridge Company and then spent three years with the Pittsburgh Testing Laboratory, serving as a resident engineer for that concern in Chicago, Illinois, Atlanta, Georgia, Philadelphia, Pennsylvania, and then Buena Vista, Virginia. Feeling the need of more practical knowledge of the manufacture of steel, he entered the employ of the Lewistown Steel Works at Lewistown, Pennsylvania, where he spent a year working by special arrangement with the managers, through every department of the mills. During the next eight or nine years he was associated with many of the best known steel and bridge manufacturing firms of the Pittsburgh District, i. e. the Carnegie Steel Company, the Keystone Bridge Company, The Fort Pitt Bridge Company, Jones & Laughlin Steel Company, The Marshall Foundry & Construction Company and gave some service as a consulting engineer.

From 1901 to 1917, Mr. Barbour was employed in the office of the Carnegie Steel Company as a mechanical engineer, head of the Drafting Department, structural engineer. During this period he devoted his evenings and spare hours to the invention, perfection and patenting of between 20 and 30 devices for rail and steel manufacture and steel and concrete structural details. These are listed as follows: Interlocking metal sheet piling;

Rail joints; Metal gangway supports for mines; Metallic clip fastenings; Rolling mills; Apparatus for reinforced composite slabs; Method for rolling flanged sections; Composite structures; Railway tract construction; Methods of bending flanged shapes; Building structures; Railway tract structures and methods of making same; Methods of rolling flanged sections; Rail ties; Rail joints; Methods of rolling flanged shapes; H shapes; and the like. Half a dozen others have been sold or the patents have lapsed. All Mr Barbour's patents were handled, for his protection, by the firm of Bakewell and Byrnes, Attorneys.

In 1917, Mr. Barbour severed his connection with the Carnegie Steel Company and took up some special work for the Dravo Construction Company. That work completed he was employed by The H. Koppers Company, during the remainder of the war period and then entered the employ of the Schaeffer Engineering and Equipment Company, which was later absorbed by the Fawcus Machine Company. He was with this firm when he developed a most malignant form of cancer of the liver and died April 19, 1921, after four months of illness. He attended his office and performed his routine work until just a month before his death. During his young manhood, Mr. Barbour's tastes were strongly literary and he wrote and published many verses. The majority of these appeared in the Pittsburgh newspapers and he was chosen as official poet for several public occasions. He published three small volumes, "Songs and Sonnets," "From the Manger to the Grotto" and "The Mound Builders."

He was a vestryman in Saint Andrew's Episcopal Church, a member of the Engineers' Society of Western Pennsylvania and the American Society of Mechanical Engineers.

In 1898, Mr. Barbour married Miss Eleanor Gerwig of Allegheny. His widow, four children, Katherine, Joseph, Florence, and William, three sisters and one brother survive.

William Glyde Wilkins.

William Glyde Wilkins was born in Pittsburgh on April 16, 1854, at 71 Fourth Street (now Fourth Avenue) Pittsburgh, the son of Alvin and Charlotte Glyde Wilkins. He died at his residence, 941 North Lincoln Avenue, Pittsburgh on April 12, 1921.

He, with his parents, moved to Detroit in 1855.

He was educated in the public schools of the latter city. In September, 1872, he entered the Rensselaer Polytechnic Institute at Troy, New York, where he remained for one year. He then entered the employ of the Munsing Iron Company, Lake Superior, where he served two years. He then entered the employ of the Pennsylvania Lines at Pittsburgh under Felician Slataper, Chief Engineer. In September, 1876, he returned to Rensselaer and took up his course where he had left it. He graduated in 1879 with the degree of Civil Engineer.

Upon his graduation he entered the service of the United States and was assigned to a party making a hydrographic survey of the Mississippi River in the vicinity of Fulton, Tennessee. While he was in this service the Mississippi Commission was created and the party with which he was connected was assigned to service with the Commission.

He left this employment in June, 1880, and joined the Engineering Department of the Pennsylvania Railroad as Assistant Enginner of Construction at Philadelphia. He remained with this company for seven years, and in July, 1887, he returned to Pittsburgh where he made his home for the balance of his career.

He opened an office on Fourth Avenue and it is interesting to relate that this office was on the same side of the street as his birthplace and within three hundred yards of the same. He was successful in his practice from the start.

On January 1, 1890, he associated with him Geo. S. Davison, a member of this Society, and the business was carried on under

the firm name of Wilkins and Davison. This firm moved into the Westinghouse Building, corner of Penn Avenue and Ninth Street, on April 1, 1890, at which location the business thus established is still being conducted.

Shortly after Mr. Davison's retirement from the firm, on January 1, 1900, the business name of the concern was changed to The W. G. Wilkins Company, Mr. Wilkins associating with him Jos. F. Kuntz and Wilbur M. Judd, both members of this Society.

During his service with the Pennsylvania Railroad, he had charge of the construction of many important works, among them being the Duquesne Freight Station in this city, and the stone arch bridge on the main line of the Pennsylvania Railroad at Johnstown.

While Mr. Wilkins' practice covered every branch of engineering, he had a strong inclination toward architecture, and through his efforts his firm established a valuable practice in that art. Perhaps one of the best examples of his work and the one that is most highly appreciated by his fellow alumni of Rensselaer Polytechnic Institute is the Pittsburgh Building on the campus of the Institute, the design and superintendence of which he contributed to his alma mater.

His experience with the Pennsylvania Railroad naturally fitted him for railroad work and his firm can point to many railroad enterprises in Western Pennsylvania, West Virginia and Ohio which were located and constructed by it.

But above everything else Mr. Wilkins was passionately fond of serving the coal and coke interests, and he became an authority on the development of shaft mining and coking plants. In the early days of his practice he was called upon to design a head frame for a company that was already in the coke business and was operating old style wooden head frames. Mr. Wilkins, with many misgivings on the part of the owners, persuaded them to allow him to construct a steel head frame. This was the first of the many steel head frames that have been constructed in this country.

His complete knowledge of the coking business caused his appointment in 1907 as one of the three Trustees of the Estate of William Thaw, Deceased, Coke Trust, a concern which, as is well known, owns and leases many thousands of acres of coal lands in the Connellsville Coke Region. He continued as Trustee until his death.

During a temporary vacancy in the office of the City Engineer of Allegheny, much against his desires he consented to perform the duties of the office. This he did very acceptably. Many extensive public improvements were carried through during this time, among others being the Perrysville Avenue improvement.

In addition to his membership in this Society he was a member of the American Institute of Consulting Engineers, American Institute of Mining and Metallurgical Engineers, American Mining Congress, North of England Institute of Mining and Mechanical Enineers, Coal Mining Institute of America, Academy of Science and Arts of Pittsburgh, and the American Society of Civil Engineers. In the latter Society he served as a Director during the years 1909, 1910, and 1911.

Mr. Wilkins took great interest in the civic affairs of the community. He was a member of the Pittsburgh Flood Commission from the time of its formation in 1908 to the end of his life. He served actively on the Engineering Committee and assisted in the exhaustive study of the water sheds of the Allegheny and Monongahela Rivers, which dealt with a plan for controlling the flood waters of these streams through the construction of impounding reservoirs.

He was an active member of the Chamber of Commerce of Pittsburgh and served as a Director of this body for the period from 1908 to 1914.

As a member of the various committees of the Engineers' Society of Western Pennsylvania which were appointed to report on civic matters and conditions of this city, he took part in many recommendations for the public good.

It might be said of him that no other individual made so exhaustive a study of the plans and prospects of the Lake Erie and Ohio River Ship Canal. The conclusions he reached about this project raised serious doubts as to its feasibility and he wrote and published, at his own expense, several documents which were so clear and forceful that he won many adherents to his views.

At the session of the Pennsylvania Legislature in 1911, the City of Pittsburgh was granted a new charter, which abolished the plan of entrusting the legislative work of the City of two large bodies of councilmen, and placed the work in the hands of nine councilmen to be elected at large. Mr. Wilkins was a member of the first body, which was appointed by the Governor on June 5, 1911. At the expiration of his commission he was elected by popular vote and continued in office until December 31, 1915.

No finer tribute could be paid his services as a public man, than a portion of the resolutions adopted by the City Council with reference to his demise.

"In public office and in his professional life, Mr. Wilkins stood always for the constructive betterment of this community and was a worthy representative of that type of citizenship to which Pittsburgh owes much of its present greatness, and upon which in a large measure, the future growth and prosperity of our City depends."

He was a great lover of books and possessed one of the largest private libraries in Pittsburgh. While this library was very extensive as to engineering subjects, it was noted throughout the country as being one of the most complete collections of the works of Charles Dickens, and Mr. Wilkins was internationally recognized as being the best informed student as to this author. He wrote profusely and delivered many lectures on Dickens.

He was elected a member of the Engineers' Society of Western Pennsylvania in May, 1887. He was President of the Society in the year 1896, and served as a Director for several years previous.

He is survived by his wife, Sarah Rebecca Simmons of Troy, N. Y., to whom he was married on December 29, 1880.

Francis Z. Schellenberg

Born, Philadelphia, Pa., Nov. 29, 1837.
Died, Pittsburgh, Pa., Nov. 15, 1921.
Joined the Society February, 1882.
Director—1907, 1908 and 1909.

Mr. F. Z. Schellenberg, dean of the consulting engineers of the Pittsburgh District, died at the home of his daughter, Mrs. Elizabeth S. McGinnis, 237 N. Dithridge St., Pittsburgh, Pa.

Mr. Schellenberg was born in Philadelphia, Pa. of German parents. He was educated in the common schools of that city and at the Polytechnic College of Pennsylvania, where in 1859, he received the degree of civil engineer. The only surviving member of the class of 1859 is Dr. Daniel Carhart a member of the Society.

During the following eight years he was employed in railroad surveys and construction in New Jersey and in Pennsylvania. In 1862, he volunteered for service in the Northern Army and camped with his regiment in great discomfort before the battle of Antietam. In 1867, Mr. Schellenberg was employed by the Westmoreland Coal Co. at Irwin as mining engineer. He served this company in the capacity of engineer and later as General Superintendent for a period of twenty-one years. The company at that time employed 1200 men.

During this time, the employes under Mr. Schellenberg organized the first Miners' Relief Fund, by compulsory contributions of all employes. The company contributed an amount equal to that of the employes and benefits covered accidental deaths, disability, etc.

In 1871 Mr. Schellenberg married Miss Mary DeC. Foster, daughter of the Hon. Henry D. Foster of Pennsylvania. Mrs. Schellenberg died at Pittsburgh March 9, 1899, leaving two daughters Elizabeth (Mrs. McGinnis of Pittsburgh) and Emelie (Mrs. Paul of Buffalo, N. Y.) and a son Frank F. (who was graduated at Princeton in 1902 and has adopted the profession of Civil Engineer). All three of Mr. Schellenberg's children survive him.

In 1888, he removed to Pittsburgh and entered into private practice as consulting engineer. He was possessed of a most remarkable memory and so devoted himself to his professional work, that it was said of him that at one time, he could discuss from memory the conditions in any principal entry of any mine in the Pittsburgh District. He was consulted by many of the large corporations of this region, on matters of mining and railroad engineering and sent to make reports on properties in thirteen states, including far western and north-western states, besides the Canadian Northwest and Northeast. Mr. Schellenberg served on the Pennsylvania State Commission which prepared the Mining Laws of 1893 governing all Bituminous mines. While still living in Irwin, Mr. Schellenberg joined the Engineers' Society of Western Pennsylvania in 1882, and continued as an active member until a few years before his death, frequently contributing to its papers and discussions and serving as a director for three years 1907, 1908 and 1909.

Mr. Schellenberg was an active worker in several other technical societies. For three years he was president of the Coal Mining Institute of America and frequently contributed to its proceedings. He was also a member of the Philiosophical Club of Pittsburgh, The Botanical Society of Western Pennsylvania, the Technicher Verein of Pittsburgh and the German Club of Pittsburgh. He was a frequent contributor to the discussion and publications of all these Societies. Although he had never been abroad and was entirely self taught, he became very proficient in the German language and some of his technical work in that language was reprinted in Berlin.

Mr. Schellenberg was a man of rigid probity, gentle manner and kindly sympathy. With a devotion to culture, he combined a keen sense of humor. He was a most interesting companion and staunch friend. He delighted to help young men and a host of friends mourn his passing.

BOARD OF DIRECTION.

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms (Parlor B) William Penn Hotel, Thursday, January 5th at 4:10 P. M., President George H. Danforth presiding, Messrs. James, Fohl, Spellmire, Schatz, Hunter, Stucki, Blum, Hawley and the Secretary being present.

The Minutes of the last regular meeting held December 1st. were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, purusant to the action of the Board were elected to membership.

MEMBERS

Burner, William J.
Forbath, Elmer F.

JUNIOR

Lundgren, E. H.

The applications of the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Clair, Charles Edwin	Lyon, Dugald
Kanarr, Harry Mortimer	Schnicke, Robert

ASSOCIATE MEMBER

Hammil, Fred W.

Letters of resignation were received from the following members and after discussion, were ordered accepted: C. J. Brown, S. Buka, Philip O. Davis, R. Marsland.

Requests for reinstatement were received from the following gentlemen and the Board requested that letters be written advising them that they had been reinstated to membership: S. S. Baker, S. L. Fuller, Richard Hirsch.

The Secretary reported the death of Mr. J. S. Cunningham who joined the Society May, 1914 and died Dec. 13, 1921.

The reports of the Secretary showing the financial condition of the Society at the close of business October 31st and November 30th, having been previously audited by the Finance Committee, were approved.

The Secretary reported verbally on behalf of the Entertainment Committee stating that the list of speakers have been completed for the banquet and notices mailed out. Up to the present time, reservations have been received for about 300 people, which is somewhat ahead of the record of previous years. The Committee is to hold a meeting next week at which all details for the dinner will be completed. It is expected that Governor Sproul and W. W. Atterbury will be honor guests.

The Secretary reported for the Finance Committee to the effect that there was a deficit for the year 1921 of approximately $6000. This is made up of $130.00 entrance fees, which should have been transferred to the

Permanent Fund; $2400 borrowed from the Permanent Fund during this year and last year; $1000 received in Life Memberships which must be repaid in the Permanent Fund and about $2500 to $3000 in unpaid bills.

Mr. Schatz, Chairman of the House Committee reported an evening attendance of 93 for the month of December.

During the past month the Committee has had all the furniture in the Room gone over and refinished where it is needed, together with some repair work. This work was done free of charge through the courtesy of the Jos. Horne Co.

Mr. Hunter, Chairman of the Membership Committee, reported verbally stating that due to his illness and other matters, the committee had not been able to carry out any of the plans suggested but hoped to start on the work in the near future.

On motion the meeting adjourned at 5:00 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING

The Forty-Second Annual Meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Monday, January 16th, at 8:20 P. M., President George H. Danforth presiding, 69 members and visitors being present.

The Minutes of the last Annual Meeting held January 18, 1921 were read and approved.

The Annual Report of the Board of Direction, which included the reports of the Standing and Special Committees the Sections and the Treasurer, were read as follows:

REPORT OF BOARD OF DIRECTION

The Board of Direction of the Society held ten regular and three special meetings during the year, at which routine business of the Society was transacted.

During the year there were nine regular and the Annual Meeting of the Society. The total attendance was 674, the average being 67. The maximum attendance was 420 at the November meeting and the minimum 47 at the December meeting. The average number participating in the discussion of the papers was six.

At the close of the year, the membership of the Society was as follows:

Honorary Members	1
Members	1131
Associate Members	90
Associates	27
Juniors	74
Student Juniors	2
Total	1325
Dropped	None
Resignations	53
Removed by death	16
Total	69
Accessions	214

Respectfully submitted,

K. F. Treschow, *Secretary.*

REPORT OF HOUSE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

The evening attendance in the Society Rooms for the past year was 561.

Two new chess tables and glass tops for the four tables in the Society Rooms were presented to the Society by Mr. Schatz.

During the year the House Committee held several meetings with the Finance Committee on matters in connection with the finances of the Society and a joint report was presented to the Board of Direction giving certain recommendations in regard to our finances.

A Chess Tournament was held in the Society Rooms and prizes awarded to the two best records made. Mr. A. Stucki was awarded the first prize, an engraved silver vase filled with American Beauty Roses presented by Mr. Danforth, and the second prize was awarded to Mr. H. R. Thayer, a set of ivory chess men presented by the Federal Engineering Co.

In April of this year the committee called on Mr. Shaw, renting agent of the Frick Estate with reference to our lease which was to expire April 1, 1922, and was informed that our rent would be increased from $3204.00 to $5306.00 for the quarters we were then occupying in the Union Arcade Building. This amount also excluded the use of an auditorium which, under the old lease, the Union Arcade were paying for. As the rent of an auditorium would cost approximately $1200 per year, our rent would have been $6500.00 per year. Inasmuch as this amount was beyond our present means, the House Committee reported at the April meeting of the Board of Direction with the result that they were asked to call a joint meeting with the Finance Committee and make a careful study of our finances and the possibility of securing other quarters. After a careful study and thorough canvass of the city, at which time all the principal buildings were covered, it was found that the most favorable proposition had been presented by the William Penn Hotel, which offered us the room we are now occupying together with the Blue Room forty times a year for meetings and a private parlor for meetings of the Board of Direction, at $3600.00 per year or about 60% of what it would have cost to remain in the Union Arcade. The Committee believes that the Society has benefited by our move to the Hotel and feels that we will be able to offer certain club privileges which we have not been able to give in the past and they have already made certain arrangements, details of which will be announced later. We might add at this point that the evening attendance in the rooms has increased 100% since moving into the hotel.

Respectfully submitted,

FRED C. SCHATZ, *Chairman.*

REPORT OF PUBLICATION COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

During the year, two meetings of the Committee were held with an average attendance of eight.

Papers presented at the General Society meetings	10
Papers read at various Sections	27

Nine meetings of the Practising Engineers' Section were held to discuss the business of the Section, no papers being presented at these meetings. Twenty-three of the above papers have been published in the Proceedings of the Society, or will appear in later issues.

On account of the printers' strike, publication of the proceedings has been very much delayed, but we expect to be up to date by the middle of February.

Respectfully submitted,
L. F. W. Hildner, *Chairman.*

REPORT OF MEMBERSHIP COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

An effort was made by the Committee to get the executives of some of the larger companies and prominent engineers interested in the Society by sending to them an invitation card asking them to join the Society without filling in an application blank. Thirty-five such invitations were sent out, eleven of which were accepted.

The Board of Direction continuing their remittance of entrance fees to local members of national engineers' societies residing in this district, it was decided to send out invitations to such members. Five hundred letters were sent out asking them to join the Society by simply filling out a card. Ninety-two cards were received, forty from the A. S. M. E., twelve from the A. I. M. & M. E., fifteen from the A. S. C. E. and twenty-five from the A. I. E. E.

The Committee also recommended that a Student Section be formed of the students attending the University of Pittsburgh, Carnegie Institute of Technology, and the Apprenticeship Courses at the Westinghouse Elec. & Mfg. Co., and was authorized to form such a section. Due to the financial condition of the Society no definite action has been taken on this recommendation up to the present time.

At the close of the year, the membership of the Soociety was as follows:

Honorary Members	1
Members	1131
Associate Members	90
Associates	27
Juniors	74
Student Juniors	2
	1325
Dropped	None
Resignations	53
Removed by death	16
	69
Accessions	214

The Committee feels that the Society should have at least twice as many members, and for this reason it would like to suggest that each member of the Society make an effort to have all engineers of their acquaintance become members. In addition to the advantages received by being associated with engineers and belonging to an engineers' society, the committee would call attention to the new quarters in the William Penn Hotel, which offers a club room conveniently located for the use of the members.

Respectfully submitted,
John A. Hunter, *Chairman*

REPORT OF CIVIC AFFAIRS COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

The Committee held only one meeting during the year at which were discussed the three propositions presented by Mr. R. J. Allderdice, Director, Department of Public Safety, City of Pittsburgh on

1st. Widening of Water Street
2nd. Widening of Duquesne Way
3rd Using wharves as at present for parking purposes.

The Committee recommended that the third proposition be approved, but stated that it would be best to not approve the first two propositions until after the widening of Second Ave., as they would then be in a better position to make recommendations.

Respectfully submitted,

J. D. Martin, *Chairman.*

REPORT OF FINANCE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

Your Finance Committee begs to submit the following report of work done during the past year.

The Finance Statements of the Secretary have been audited monthly and found to be correct.

At the April meeting of the Board of Direction, the House Committee reported that they had been informed by Mr. Shaw of the Estate of H. C. Frick that our rent was to be increased at the expiration of our present lease April 1, 1922 from $3200 to $5300, not including the use of an auditorium which would make our total rent approximately $6500 per year. After a general discussion of the Financial conditions of the Society it was recommended at this meeting that the House and Finance Committees make a joint investigation as to the financial condition of the Society and the possibility of securing other quarters at rent within our means.

These committees held several meetings during which a careful study of expenditures and receipts for the past fifteen years was made and a number of detailed reports were made up by the Secretary showing receipts for the past fifteen years divided into dues, entrance fees and miscellaneous Classification of dues based on membership December 31, 1920, record of membership 1907 to 1921 giving new members, resignations, loss by death, dropped, and net gain or loss by years. Detailed account of expenditures for the past fifteen years and a summary showing total membership, total receipts and expenditures, and average cost per member.

An analysis of these reports showed that while our receipts had had a steady increase in accordance with the growth of the Society, which averaged a net gain of approximately 38 a year during the period under investigation, our expenditures showed a rapid rise between the years

1919 and 1920. The cost per member in 1919 being $10.69 and in 1920 $15.21 per member. In looking about for relief, it was discovered that this increase was due almost entirely to the increased cost of printing, which jumped from $2735.90 in 1919 to $5360.88 in 1920. It might be pointed that our five year contract with the printer expired December 31, 1919.

Other items of expense were found to have had but a slight increase in accordance with the increased activities of the Society. It must be remembered that these increased expenditures were prior to the proposed increase in rent which the report of the Chairman of the House Committee will show amounted to more than 100%, and even with the change that has been made by moving into the William Penn Hotel, the Society stands obligated to an increase of $400 a year in rent. In regard to the increased cost of printing, the Publication Committee in January, 1921 secured bids from thirty-two printers in Pittsburgh, Philadelphia, Baltimore Greensburg, Latrobe and Crafton with the result that it was found our present printer was doing the work from 25c to $5.00 a page cheaper than any bids received.

Consideration of these facts by the Committees resulted in the following recommendation being made at a special meeting of the Board of Direction held in June of this year:

"In view of the findings of the Committees as given in the above report, together with the data on finances mailed to each member of the Board of Direction, the Committees recommends that the dues be increased $2.50 per year and further that our present quarters be cut down by releasing either part or all of our present club room in order that our expenditures may be kept within our income."

This matter was discussed at length at this meeting with the result that the members of the Board felt that an increase in dues should be avoided if at all possible and the Committees were asked to go into these matters further.

The Chairman of the Finance Committee would feel that his duties were not fully discharged unless some attempts were made to show the members the financial standing of the Society at the present time, and the following extract from the report of our auditors, who have just completed their annual audit of the accounts of the Society, puts this very clearly, and

"The above deficit ($2420.82) apportioned to the averaged membership of 1250 for the eighteen months ending December 31, 1921 results in a net loss of approximately $1.94 per member, excluding interest received, entrance fee, life membership and income from practising engineers, which should not be considered as normal income the net loss would be $5863.01 or approximately $4.62 per member."

It will be seen from the report of the House Committee that all possible has been done in regard to quarters. No further reduction can be hoped for in rents. Unless essential activities of the Society are to be curtailed, no reduction of moment can be hoped for in printing. No increase of membership in a number sufficient to meet our difficulties seems possible.

It therefore appears to the Chairman of the Finance Committee no other alternative but to renew the recommendations made at the special meeting of the Board of Direction that the dues be increased and he is quite certain that the increase proposed is none too large.

Respectfully submitted,

WM. E. FOHL, *Chairman.*

REPORT OF ENTERTAINMENT COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

The following entertainments were held during the past year:

January 16th—Annual Banquet—Paid attendance, 749.

April 2nd—Inspection trip—Colfax Plant, Duquesne Light Co. Attendance 300.

June 4th—Inspection Trip—Beech Bottom Power Co. plant, Wellsburg, W. Va. Attendance 132.

June 8th—Boat Excursion—Steamer Sunshine—Attendance 90.

September 3rd—Inspection Trip—Government Locks and Dams at Emsworth. Attendance 104.

On account of business depression, other inspection trips and entertainments were not held.

Respectfully submitted.

WALTER B. SPELLMIRE, *Chairman.*

REPORT OF GOVERNING COUNCIL ASSOCIATED ENGINEERING SOCIETIES OF PITTSBURGH

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

Organization meeting held April 28th.

Five meetings of the Council were held during the year.

April 28th—Organization meeting.

May 28th—Meeting held to discuss the question of the Government presenting either a part or all of the Arsenal property to the City for use as an approach for the Bridge at 40th Street, or selling it to the City for a nominal sum. Three members were appointed to attend the meeting held in Washington to consider the matter.

June 13th—Meeting held to discuss plans of Boulevard of the Allies, known as high level and low level plans submitted by Director Brown of the City of Pittsburgh. Resolution adopted recommending the high level plan, as it was thought traffic could be better taken care of in this way.

June 22nd—Meeting called to discuss question of suggesting names to Governor Sproul for appointment on the Engineering Board to be appointed in accordance with recent Act passed Licensing Engineers in the State of Pennsylvania. Letter was written Governor Sproul sending list of names as suggested.

Committee also inspected plans in the City-County Building for the New Boulevard of the Allies and also the completed model made by the Jones & Laughlin Steel Co.

October 4th—Meeting called to discuss the Major Street Plan of the Citizens' Committee on City Plan of Pittsburgh and recommendations made that Council endorse said plan and urged the City of Pittsburgh to give this plan their consideration when making alterations, improvements or other changes in the present street system.

Respectfully submitted,

GEORGE H. DANFORTH, *President, Governing Council.*

REPORT OF TREASURER

To the Board of Direction,

Engineers' Society of Western Pennsylvania:

Dear Sirs:

Your Treasurer begs to submit the following financial report of the Society for the year ending December 31st, 1921:

Receipts

Dues collected	$12,419.53
Life Memberships	900.00
Entrance Fees	745.00
Sale of Advertising Space	836.13
Sale of Magazine "Proceedings"	613.09
Sale of Society Pins	117.52
Interest on Bonds	732.50
Interest on Bank Balances	121.98
Sale of Boat Excursion Tickets	152.00
Income from Banquet	5,222.00
Income from Dinner-Dances, etc.	500.20
Received from Practising Engineers	194.74
Miscellaneous	38.60
Total Receipts	$22,593.29

Disbursements

Administrative and General	$12,048.93
Sectional Expenses:	
Mechanical Section	278.01
Civil Section	298.95
Metallurgical and Mining Section	210.59
Practising Engineers' Section	96.67
Steel Works Section	146.72
Cost of Magazine "Proceedings"	3,837.37
Entertainment Expenditures	5,950.64
Total Disbursements	$22,867.88
Excess of Disbursements over Receipts	274.59

Assets

	Dec. 31, 1920	Dec. 31, 1921
Permanent Fund		
Bonds	$13,738.00	$13,738.00
Cash (Fidelity T. & T. Co.)	1,514.71	2,194.71
Reserve Fund		
Cash (Fidelity T. & T. Co.)	1,200.00	100.00
General Fund		
Cash (Diamond National Bank)	201.26	302.79
	$16,653.97	$16,335.50
Decrease in Assets		318.47
	$16,653.97	$16,653.97

INVESTMENTS

Bonds Owned—Permanent Fund

One $1000 U. S. Liberty Bond 4¼% No. 54437, maturing September 15, 1928	$ 973.00
One $1000 Butler Water Company 5% Bond No. 9, matures September 2, 1931	750.00
Two $1000 Connellsville Water Company 5% Bonds Nos. 317 and 318, maturing October 1, 1930	1,500.00
Two $1000 Portsmouth, Berkley & Suffolk Water Co., 5% Bonds Nos. 465-466, maturing November 1, 1944	1,800.00
Two $1000 Jamison Coal & Coke Co., 5% Bonds Nos. 1502 and 1503, maturing November 1, 1931	1,940.00
Two $1000 Union Steel Co., 5% Bonds Nos. 38642-38643, maturing December 1, 1952	2,025.00
Two $1000 Pennsylvania Railroad Co., 4½% Bonds, Nos. 27320 and 27321, maturing August 1, 1960	1,870.00
Three $1000 Jones & Laughlin Steel Co., 5% Bonds, Nos. 3020-3021 and 3022, maturing May 1, 1931	2,880.00
Total Securities Owned	$13,738.00

Due to the increased cost of printing and rent and to the fact that our dues were not increased since 1913, we have a deficit this year of about $6000.00 A detailed statement of this deficit was presented by the Chairman of the Finance Committee so that it will be unnecessary to repeat it here.

Our bonds show a slight improvement over last year.

Respectfully submitted,

A. Stucki, *Treasurer.*

REPORT OF CIVIL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

I beg to submit the report of the work done by the Civil Section during the year 1921.

Five regular meetings of the Section were held during the year. The average attendance at these metings was 75, the maximum being at the January 4th meeting, 108, and the minimum 22 at the May 3rd meeting.

An average of seven participated in the discussion of the several papers presented. The papers presented during the year were:

January 4th—Annual Meeting. "Erection Methods for Heavy Viaduct and Bridge Construction Showing Erection of Belly River and Deep Creek Viaduct and the Quebec Bridge." By George F. Porter, Chief Engineer, Canadian Bridge Co., Ltd., Walkerville, Ont.

March 8th—"Aerial Photography as Applied to Surveying." By J. Bradley Mandeville, Chief Engineer, T. W. Phillips Gas & Oil Co., Butler, Pa.

May 3rd—"The Miles Acid Process of Sewage Treatment." By Dr. E. W. Mohlman, Chief Chemist, Sanitary District of Chicago, Chicago, Ill.

October 11th—"The Erection of the 33rd Street Bridge Allegheny River Crossing of the B. & O. R. R. at Pittsburgh." By J. L. deVou, Division Erection Manager, American Bridge Co., Pittsburgh, Pa.

November 8th—"The Traffic Count of Pittsburgh." By Winters Haydock, Engineer, Citizens' Committee on City Plan of Pittsburgh, Pittsburgh, Pa.

Respectfully submitted,

L. P. Blum, *Chairman.*

REPORT OF MECHANICAL SECTION

To the Board of Direction,

Engineers' Society of Western Pennsylvania:

Dear Sirs:

I beg to submit the report of the work done by the Mechanical Section during the year 1921.

Four regular meetings of the Section were held during the year. The average attendance at these meetings was 113, the minimum being 62 at the April 5th meeting and the maximum 205 at the October 4th meeting.

An average of seven participated in the discussion of the papers presented. The papers presented during the year were:

February 1st—Annual Meeting. "A Dscription of the Large Boilers Operating at the River Rouge Plant of the Ford Motor Company." By George T. Ladd, George T. Ladd Co., Pittsburgh, Pa.; E. C. Keithley, Locomotive Superheater Co., New York; H. D. Savage, Combustion Engineering Co., New York.

April 5th—"Explosion Hazards in Industrial Plants Due to Use of Pulverized Coal." By L. D. Tracy, U. S. Bureau of Mines, Pittsburgh, Pa.

June 14th—"Some Properties and Uses of Monel Metal." By R. J. McKay, Ind. Fellow, Mellon Institute, Pittsburgh, Pa.

"Calorizing as a Protection for Metals." By A. V. Farr, Mechanical Engineer, The Calorizing Co., Pittsburgh, Pa.

October 14th—"Power Station Design." C. W. E. Clarke, Power Engineer, Dwight P. Robinson Co., New York, N. Y.

Respectfully submitted,

J. C. Hobbs, *Chairman.*

REPORT OF MINING SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

I beg to submit the report of the work done by the Mining Section during the year 1921.

Four meetings of the Section were held during the year. The average attendance at these meetings was 38, the maximum being 52 at the March 29th meeting and the minimum 22 at the June 25th meeting.

An average of five participated in the discussion of the papers presented. The papers presented were:

January 25th—Annual Meeting. "Coal Mine Explosions." By J. W. Paul, Coal Mining Engineer, U. S. Bureau of Mines, Pittsburgh, Pa.

March 29th—"Coal Washing—Its Objects, Methods and Accomplishments." By Paul Stewart—Assistant Chief Engineer, Roberts & Schaefer Co., Chicago, Ill.

June 28th—"Description of Mather Collieries Plant." By J. R. Elliott, Baton & Elliott, Pittsburgh, Pa.

November 29th—"The Lynch Plant of the United States Coal & Coke Co." By H. N. Eavenson, Cons. Mining Engineer, Howard N. Eavenson and Associates, Pittsburgh, Pa.

Respectfully submitted,

J. D. MARTIN *Chairman.*

REPORT OF PRACTISING ENGINEERS' SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

I beg to submit the report of the work done by the Practising Engineers' Section during the year 1921.

Two meetings of the Section were held, two being open meetings, the others being held to discuss the framing of and introducing into the Legislature the bill which has since been approved by the Governor, for the regulation of engineering practice; also various matters coming up in connection with the work of the engineers in private practice.

The average attendance at these meetings was 25, the minimum being 10 at the September 21st meeting and the maximum 60 at the March 8th meeting.

At the two open meetings the following papers were presented:

November 22nd—"A Major Street Plan for Pittsburgh." By C. L. Wooldridge, General Superintendent, Carnegie Land Co, Pittsburgh, Pa.

March 8th—"Aerial Photography as Applied to Surveying." By J. Bradley Mandeville, Chief Engineer, T. W. Phillips Gas & Oil Co., Butler, Pa.

At these meetings the average number participating in the discussion was ten,

Respectfully submitted,

C. E. LONG. *Chairman.*

REPORT OF STEEL WORKS SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

I beg to submit the report of the work done by the Steel Works Section during the year 1921.

Three meetings of the Section were held. The average attendance at these meetings was 101, the maximum being 126 at the April 26th meeting and the minimum 82 at the October 25th meeting.

An average of five participated in the discussion of the papers presented.

The papers presented were:

February 28th—Organization Meeting. "Distribution and use of Coke Oven Gas." By Strickland Kneass, Jr., Steam Engineer, Youngstown Sheet & Tube Co., Youngstown, Ohio.

April 26th—Joint Meeting A. S. M. E. and Section. "Possibilities of Improved Methods of Rolling Sheet Steel." By Sumner B. Ely, Visiting Professor, Mechanical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

October 25th—"Heating Furnaces—Design and Practice." By Dr. C. M. Stein, Engineer, Paris, France. (Presented by Mr. W. B. Chapman, President, Chapman Engineering Co., in the absence of Mr. Stein).

Respectfully submitted,

T. P. Davies, *Chairman.*

REPORT OF TELLERS

To the Members,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

The undersigned tellers publicly canvassed the ballots in the annual election of officers of the Society at noon, Monday, January 16th, 1922, and beg to report the following results:

Ballots received	329
Irregular ballots	10
Ballots counted	339

For President	Henry D. James	325
For Vice President	Frederic Crabtree	327
For Treasurer	A. Stucki	328
For Directors	J. C. Hobbs	326
	C. D. Terry	326

Respectfully submitted,

Charles C. Dornbush, Chairman;
E. D. Leland,
J. A. McEwen
Tellers.

The President thereupon declared the following men elected:

For President..Henry D. James
For Vice President......................................Frederic Crabtree
For Treasurer..A. Stucki
For Directors...J. C. Hobbs, C. D. Terry

Before the new president was escorted to the chair, Mr. Danforth addressed the Society as follows:

I would particularly call your attention to the report of the Finance Committee,—they have had some trying times to contend with and the work is not finished, I do not want you to think that the Society is bankrupt, for it is still far from being in that condition, but the facts are as shown by the report, that for two years back we have been exceeding our income, due to the increasing costs of everything that the Society requires to carry on its work This has been aggravated by the difficulties in collecting the dues, which is accounted for by lack of business for our members. There is a decided opposition to an increase in our dues and the opposition is well founded, but if the increase is to be avoided, we will have to have one of three things happen—first, a large increase in our membership, which I would like to see, but do not know how it can be brought about; second, a prompt payment of this year's dues as well as paying up of those that are in arrears and third, an attendance at our entertainments that will put them in the position where they are a financial benefit to the Society instead of a financial drag. If this can be brought about, there need be no serious curtailment of the Society's activities which curtailment would be seriously regretted. I have only to tell you that the cost of operating the Society has risen from $10.69 in 1919 to $15.21 in 1920 with a slight recession in 1921 to $1500.; these figures being on a per capita basis.

The president then appointed Mr. Neilson and Mr. Stucki to escort the president elect to the chair. Mr. Henry D. James being duly installed as President addressed the Society as follows:

This ceremony is always very pleasant for the incoming president. It is a great pleasure for any engineer to be elected to the presidency of our Society.

We have listed some good reports this evening and they are all very encouraging with the exception of the financial report. The recommendation of this committee for an increase in dues is a logical conclusion to be drawn from our existing financial status, but I believe we will find another solution for this difficulty and I am certain the other members of the Board agree.

At the present time we have fourteen hundred members. If we can secure a net increase of two hundred members, we can probably balance our budget. This will require only one member out of every seven in our Society securing a new man. Out of our fourteen hundred members we certainly should have two hundred who are active enough and good enough salesmen to secure one member each.

We have an excellant talking point in our new quarters at the William Penn Hotel. These quarters fulfill our long felt want for club facilities which we have obtained without any increased liabilities on our part. Adjoining our club room is the Hawaiian Room where dinner dances are held every night. We hope to organize special parties of club members, probably once a month, to enjoy an informal dinner dance. If you are fond of dance music and do not want to attend dinner, spend an evening in our club room and enjoy the music free of charge. The Secretary can

make hotel reservation for you or your guests and can also secure pullman tickets through the hotel office in the usual way. There is a cafeteria adjoining the club where you can obtain a lunch for fifty cents if you are not very hungry. Urge these advantages on our own members as well as the prospective members so that every one may take full advantage of the increased facilities afforded the members of our Society.

Now a word regarding some of our plans. It is always well for a president to get the advice of others There is no one in our Society who is more interested in our policy and progress than our two vice presidents. Both Mr. Knowles and Mr. Crabtree have agreed to act with me as an executive committee during this administration. Mr. Knowles will be chairman of the Civic Affairs Committee and Mr. Crabtree will be chairman of the Publication Committee. Mr. Hunter will continue as Chairman of the Membership Committee and Mr. Hildner will serve as chairman of the Medal Awards Committee. Mr. Hawley has consented to act as Chairman of the Finance Committee and Mr. Fohl will take charge of the House Committee. The present Entertainment Committee will serve until after the banquet. ,

The officers and directors of our Society want the active assistance of every member in developing our Society and we will welcome suggestions for increasing our service to both our members and the community. If you have any ideas and cannot communicate with me, talk them over with Mr. Knowles, Mr Crabtree or with other members of the Board. It is always well to put your suggestions in letter form and send them to the Secretary so we may have a record of them.

No further business coming before the Society, the retiring president's address was presented by Mr. George H. Danforth on Structural Steel—Its past and Future.

The ensuing discussion was participated in by: Mr. W. W. Hendrix, Sales Mgr., Pittsburgh-Des Moines Steel Co., Pittsburgh, Pa.; Mr. L. F. W. Hildner, V. P. & Chf. Engr., Pittsburgh Bridge & Iron Wks., Pittsburgh, Pa.; Mr. H. D. James, Mgr., Control Engineering Dept., Westinghouse E. & M. Co., and the author.

On motion, the meeting was adjourned until the next evening for the election of the president and officers, as according to the By Laws, the Annual Meeting should be held Third Tuesday of January.

K. F. Treschow, *Secretary.*

MINING SECTION

The Annual Meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday Jan. 31st, 8:30 P. M., Chairman J. D. Martin presiding, 18 members and visitors being present.

The Minutes of the last Annual Meeting were read and approved.

The Annual Report of the Executive Committee was presented by the Chairman.

The report of the Nominating Committee was read by Mr. J. W. Paul in the absence of Mr. Fohl, Chairman, as follows:

Officers and Members of Mining Section,
Engineers' Society of Western Pennsylvania:

Dear Sirs:

Your Nominating Committee have appointed the following nominees for the several offices of the Section for the ensuing year.

W. A. Weldin	Chairman
H. N. Eavenson	Vice Chairman
E. H. Coxe J. O. Durkee J. R. Elliott R. R. Hice R. W. McCasland	Directors

Respectfully submitted,

W. E. Fohl, Chairman;
J. W. Paul
J. M. Rayburn
Tellers.

On Motion the nominations were closed and the Secretary instructed to cast a unanimous ballot in favor of the officers named and they were, therefore, declared elected.

There being no further business, the meeting adjourned and the regular bi-monthly meeting was called to order by Chairman elect W. A. Weldin.

There being no further business, the paper of the evening on Standardization of Mine Turnouts was presented by the retiring Chairman, J. D. Martin, Chief Engineer, Hillman Coal & Coke Co., Pittsburgh, Pa.

The ensuing discussion was participated in by: J. W. Paul, Chief, Coal Mining Investigations, U. S. Bureau of Mines; W. A. Weldin, Blum Weldin & Co.; C. E. Long, Civil Engineer, Pittsburgh, Pa.; W. M. Austin, Elec. Engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa., and the author.

On motion the meeting adjourned at 9:45 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION.

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Parlor "D", William Penn Hotel, Thursday, February 2nd, at 4:10 P. M. President Henry D. James presiding, Messrs. Knowles, Crabtree, Hunter, Fohl, Ladd, Terry, Hobbs, Blum, Weldin, Long, Hawley, Danforth and the Secretary being present.

The Minutes of the last regular meeting held December 1st. were read and approved.

The applications of the following gentlemen having been regularly published to the Society, pursuant to the action of the Board, were elected to membership.

MEMBERS.

Clair, Charles Edwin
Kanarr, Harry Mortimer
Lyon, Dugald
Schnicke, Robert

ASSOCIATE MEMBER.

Hammil, Fred W.

The applications of the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows.

MEMBERS.

Carpenter, Charles A.
Carter, Emmett Browning
Dunnells, Clifford G.
Law, Stanley Overholt
Peale, Rembrandt

ASSOCIATE MEMBERS.

Berggreen, Paul Harold
Peters Ellsworth E.
Stripe, William Carl

JUNIORS

McEwen, J. D.
Stotz, Edward Jr.

Request was received from Mr. S. K. Eastwood, asking that he be transferred to a higher grade of membership. After discussion, the Secretary was requested to advise Mr. Eastwood of his transfer to the grade of Member.

The Secretary reported the death of the following members.

D. H. Amsbary,
J. W. Campbell,
E. W. Summers.

The report of the Secretary showing the financial condition of the Society at the close of business December 31st, having been previously audited by the Finance Committee, was approved.

Mr. Hawley, Chairman of the Finance Committee announced the appointment of the following gentlemen as members of the committee for the ensuing year.

A. S. Davison,
F. C. Schatz,
M. R. Scharff,
W. B. Spellmire.

Mr. Fohl, Chairman of the House Committee, reported an evening attendance of 115 for January.

Owing to the recent appointment of the Committee chairman no further reports were presented.

Mr. James brought up the matter of the change in date of Board meetings from the first Thursday to the third Tuesday of each month, stating that the reason for this suggested change was that it would enable the Secretary to make up the Finance Statement for the preceding month in time for the Board meeting instead of presenting the report a month old as at present. He also stated that by holding the meeting on this date members of the Board might take dinner together and attend the regular monthly meeting.

After a general discussion, it was moved and carried that the meeting be held on the third Tuesday of the month at 4:30 and that the Secretary send out postcard notices with the next notice of the Board asking those who wished to take dinner in the hotel to reply in order that proper arrangements could be made.

Mr. James also brought up the matter of classifying applications suggesting that this work be referred to the Membership Committee and that they meet each month to go over the applications, classifying them and presenting the list at the next meeting of the Board of Direction. This would save the time of the Board usually spent on this work and permit their using it for more important matters.

Mr. James stated that all Committee chairmen had been appointed and that the Civic Affairs Committee, of which Mr. Knowles was Chairman, expected to take an active interest in all civic matters brought to their attention and would appreciate the cooperation of the members of the Board in calling to their attention questions on which they should take action.

It was suggested that one subject which should be considered by the Committee was that of Smoke Abatement, inasmuch as there does not seem to have been much activity since the war along these lines.

The Secretary presented a letter from Mr. Richard Khuen requesting that the Board consider inviting the American Engineering Council to hold its next meeting in Pittsburgh. Mr. Khuen stated that he had received a letter from Dean Cooley, President of the Federated American Engineering Societies in which he suggested that he believed the Board would accept such an invitation if extended and felt that it would increase the interest in the Federated Engineering Societies if the Council were to meet in Pittsburgh.

After a general discussion, it was moved and carried that the President take this matter up with the various sections of the local societies in Pittsburgh and if they would agree to cooperate, that the invitation be extended.

The Secretary retired from the room while the election of the Secretary took place and Mr. K. F. Treschow was reelected Secretary at the same salary.

On motion the meeting adjourned at 5:15 P. M.

K. F. TRESCHOW, *Secretary.*

MECHANICAL SECTION.

The Annual Meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, February 7th, at 8:25 P. M. Chairman J. C. Hobbs presiding 285 members and visitors being present.

The Minutes of the last Annual Meeting were read and approved.

The Annual Report of the Section was read by the Secretary

The report of the Nominating Committee was read by Mr. H. A. Rapelye, Chairman as follows:

Officers and Members of Mechanical Section

Engineers' Society of Western Pennsylvania.

Dear Sirs:

Your Nominating Committee has appointed the following nominees for the several officers of the Section for the ensuing year.

Moore W. E., Chairman
Fox, J. H., Vice Chairman.

Dandridge, E. P.
Morton, J. A.
Patterson, P. C. } Directors
Polk, R. E.
Streeter, R. L.

Respectfully submitted,
H. A. Rapelye, *Chairman,*
W. B. Skinkle,
E. J. Stephany,
Tellers.

On motion the nominations were closed and the Secretary instructed to cast a unanimous ballot in favor of the officers named and they were, therefore, declared elected.

There being no further business the meeting adjourned and the regular bi-monthly meeting was called to order by Mr. Hobbs in the absence of Mr. W. E. Moore, chairman elect.

There being no further business, the paper of the evening was presented by Mr. Henry Kreisinger, Research Engineer, Combustion Engineering Corporation, New York and Mr. John Blizard, Fuel Engineer, U. S. Bureau of Mines, Pittsburgh, Pa. on Powdered Coal for the Generation of Steam.

Written discussion was presented by A. E. Blake, Pgh. Repr. U. G. I. Contracting Co., Pittsburgh, Pa.

The ensuing discussion was participated in by: Jos. Breslove, Consulting Engineer, Pittsburgh; J. B. Crane, Engr., George T. Ladd Co.; C. C. Emmons, Eff. Engr., Republic Iron & Steel Co., Youngstown, O.; J. R. Mason, Dist. Sales Mgr. Wickes Boiler Co.; M. F. McConnell, Supt., Carnegie Steel Co., Mingo Junction, O.; L. W. Marso, The Hardinge Co., New York, N. Y.; H. C. Cronemeyer, Designer, Jones & Laugh-

lin Steel Co., Woodlawn, Pa.; F. F. Espenschied, Pgh. Dist. Mgr., Commercial Truck Co. of Philadelphia; C. D. Reed, Steam Inspector, Duquesne Light Co.; F. J. Crolius, Steam Engr., Homestead Steel Wks. Carnegie Steel Co., Munhall, Pa.; H. R. Thayer, Markhart Thayer Engineering Co.; J. C. Hobbs, Asst. to Supt. Power Stations, Duquesne Light Co.; J. W. Paul, Chief, Coal Mining Investigations, U. S. Bureau of Mines, Pittsburgh; and the authors.

A vote of thanks was extended to Mr. Kreisinger and Mr. Blizard for their very interesting and instructive paper.

On motion the meeting adjourned at 10:42 P. M.

K. F. Treschow, *Secretary*.

CIVIL SECTION.

The Annual Meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Georgian Room, William Penn Hotel, Tuesday, February 14th at 8:20 P. M. Chairman Louis P. Blum presiding, 94 members and visitors being present.

The Minutes of the Last Annual Meeting were read and approved.

The Annual Report of the Section was read by the Secretary.

The report of the Nominating Committee was read by Mr. E. V. Braden, Chairman, as follows.

Officers and Members of the Civil Section

Engineers' Society of Western Pennsylvania.

Dear Sirs:

Your Nominating Committee has appointed the following nominees for the several officers of the Section for the ensuing year.

Reppert, C. M., Chairman.
Thayer, H. R., Vice Chairman.

Chalfant, F. B.
Ludgate, B. A.
Smith, N. G. } Directors
Buente, C. F.
Rice, J. M.

Respectfully submitted,

E. V. Braden, *Chairman*,
C. A. Martin,
P. W. Price,
Tellers.

On motion the nominations were closed and the Secretary instructed to cast a unanimous ballot in favor of the officers named and they were, therefore, declared elected.

There being no further business, the meeting adjourned and the regular bi-monthly meeting was called to order by Chairman elect C. M. Reppert.

There being no further business, the paper of the evening on Continuous-Traffic Lift Bridges was presented by A. A. Henderson, Assistant Engineer, Allegheny County, Pittsburgh, Pa.

Written discussion was received from: C. M. Reppert, Chf. Engr., Bureau of Engineering, City of Pittsburgh; Richard Khuen, General Manager Erection, American Bridge Co.; J. F. Bell, Major, Corps of Engineers, U. S. Engineer Office.

The ensuing discussion was participated in by: E. K. Morse, Engr., private practice, Pittsburgh, Pa.; Hon. William A. Magee, Mayor, City of Pittsburgh; C. A. Finley, Director, Dept. Public Works, City of Pittsburgh; A. R. Raymer, Chf. Engr., P. & L. E. R. R. Co., Pittsburgh, Pa.; H. R. Thayer, Markhart Thayer Engrg, Co.; H. D. James, Mgr., Control Engineering Dept., Westinghouse Elec. & Mfg. Co. East Pittsburgh, Pa.; J. P. Leaf, City Engr. Beaver Falls, Pa.; Winters Haydock, Chf. Engr., Citizens' Committee on City Plan of Pittsburgh; Louis P. Blum, Blum Weldin & Co.; F. L. Egan, Marine Engr., Vesta Coal Co.; and the author.

On motion the meeting adjourned at 11:12 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING.

The 401st regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Georgian Room, William Penn Hotel, Tuesday, Feb. 21st, at 8:09 P. M., President H. D. James presiding, 16 members and visitors being present.

1. The Minutes of the last regular monthly meeting held December 20th, where read and approved.

2. The Board of Direction reported the election of four applicants to the grade of Member and one to the grade of Associate Member; the receipt of nine applications for membership and the transfer to higher grade of one member. Eleven resignations were received and accepted and three deaths were reported.

No further business coming before the Society, the paper of the evening was presented by Mr. E. Atkins Starks, General Sales Manager, Durabla Manufacturing Co., New York, N. Y. on "Human Contact Point in Engineering."

The address was followed by a general discussion.

On motion the meeting adjourned at 9:45 P. M.

K. F. Treschow, *Secretary.*

PRACTISING ENGINEERS' SECTION.

The regular monthly meeting of the Practising Engineers' Section of the Engineers' Society of Western Pennsylvania was held in Parlors "E" and "F" of the William Penn Hotel, Monday evening, Feb. 27th, at 8:00 P. M., Chairman C. E. Long presiding, fifteen members being present.

Minutes of the last meeting held Nov. 30th, were read and approved.

No further business coming before the Section, the meeting adjourned at 9:00 P. M. and the Annual Meeting of the Section was called to order.

The Chairman called for the report of the Nominating Committee, which was presented by Mr. J. M. Rice as follows:

Officers and Members Practising Engineers' Section

Engineers' Society of Western Pennsylvania.

Dear Sirs:

Your Committee to report on nomination of officers for the Section reports the following:

Ross, F. G., Chairman.
Martin, P. H., Vice Chairman.
Harrop, H. S.
Long, C. E.
Jacobs, N. B.
Rankin, H. H.
Bayne, R. C.
} Directors.

Respectfully submitted,

F. M. Cooper,
J. M. Rice,
W. M. Judd,
Tellers.

It was moved and carried that the nominations be closed and the Secretary requested to cast a unanimous ballot for the officers named who were thereupon declare delected.

Chairman elect F. G. Ross then assumed the chair.

It was moved and carried that the rates adopted by the Section at the Nov. 30th meeting go into effect April 1st, 1922.

The question of meetings was brought up and discussed generally and it was moved and carried that the Section meet bi-monthly in the future beginning with the month of September and alternating throughout the year. The day for the meeting was not set and there seemed to be a diversity of opinion as to the most suitable night and it was moved and carried that the Secretary be instructed to send out a letter ballot suggesting the second Tuesday and if this proved acceptable to the membership that this night be adopted.

The question of territory to come under the jurisdiction of the rates adopted was brought up and discussed and the matter referred to the Executive Committee with the request that they define the territory in which these rates are applicable.

The meeting adjourned at 9:45 P. M.

K. F. Treschow, *Secretary.*

STEEL WORKS SECTION.

The Annual Meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday evening, Feb. 28th, at 8:23 P. M. Chairman T. P. Davis presiding, 89 members and visitors being present.

The Minutes of the organization meeting of the Section held Feb. 28, 1921 were read and approved.

The Annual report of the Section was read by the Secretary.

The report of the Nominating Committee was read by Chairman Sydney Dillon:

To Officers and Members Steel Works Section

Engineers' Society of Western Pennsylvania.

Dear Sirs:

Your Nominating Committee to nominate officers for the year beg to report the following:

Kneass, Strickland Jr., Chairman.
Goodspeed, G. M., Vice Chairman.

Backlin, A. F. Bradshaw, G. D. McKnight, Chas. Jr. McLaughlin, T. J. Shover, Barton R.	Directors.

Respectfully submitted.

Sydney Dillon, *Chairman.*
W. C. Buell, Jr.
W. C. Rott,
Tellers.

It was moved and carried that the nominations be closed and the Secretary be requested to cast a unanimous ballot for the officers named, who were thereupon declared elected.

There being no further business, the paper of the evening was presented by Dr. C. M. Johnson, Director of Research and Chief Chemist, Park Works, Crucible Steel Co. of America, Pittsburgh, Pa. on "Stainless Steels".

The ensuing discussion was participated in by: Harry C. Brearley, Metallurgist, Sheffield, England; B. M. Herr, Dist. Sales Mgr., Edward Valve & Mfg. Co., Pittsburgh, Pa.; A. E. Blake, Pgh. Representative, U. G. I. Contracting Co., Pittsburgh, Pa.; W. M. Austin, Elec. Engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa; and the author.

On motion the meeting adjourned at 10:20 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION.

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor "A", William Penn Hotel, Tuesday, March 21st, at 4:40 P. M. President H. D. James presiding, Messrs. Knowles, Crabtree, Fohl, Hunter, Hildner, Terry, Hobbs, Weldin, Ross, Hawley, and the Secretary being present.

The Minutes of the last regular meeting held Feb. 2nd, were read and approved.

Applications for membership from the following gentlemen, having been published to the Society, pursuant to the action of the Board, were elected to membership.

MEMBERS

Carpenter, Charles A.
Carter, Emmett Browning
Dunnells, Clifford G.
Peale, Rembrandt
Law, Stanley Overbolt

ASSOCIATE MEMBERS

Berggreen, Paul Harold
Peters, Elleworth E.
Stripe, William Carl

JUNIORS

McEwen, J. D.
Stotz, Edward, Jr.

Applications for membership were received from the following gentlemen and were graded by the Membership Committee as follows.

It was moved and carried that the names be published under the grades recommended by the Committee.

MEMBERS

Dawson, Joseph R.
Fechheimer, Carl J.
Geeseman, Delbert B.
Jump, Edmund Percival
McMillin, Oliver B.
White, Charles M.

JUNIORS

Haines, Elmer B.
Lappin, Joseph

Letter was received from Mr. Frank C. Schroeder for transfer to higher grade and after discussion the Secretary was requested to write him advising him of his transfer to the grade of Member.

Letters of resignation were received from the following gentlemen and it was recommended by the Membership Committee that they be accepted. It was moved and carried that the recommendation of the Committee be approved.

A. H. Anthony
J. C. Bland
W. P. Flint
S. G. Haas
S. S. Hammel
C. B. Pyle
J. Stewart

The reports of the Secretary showing the financial condition of the Society Jan. 31st and February 28th, having been previously audited by the Finance Committee, were approved.

The Secretary reported verbally on behalf of the Entertainment Committee stating that the attendance at the Inspection Trip last Saturday was 85 and had proved most interesting and instructive to those attending. Other trips are being arranged and the Committee hopes to make definite announcement of dates in the near future.

Mr. Fohl, Chairman of the House Committee reported an evening attendance in the Society Rooms of 93 for the month of February.

Two additional hat racks were purchased, as owing to the increased use of the Club Rooms, we did not have sufficient facilities for taking care of the coats and hats.

Mr. Hunter, Chairman of the Membership Committee reported that the Committee had held one meeting during the past month to consider the applications for membership in accordance with the request of the Board at its last meeting, also resignations received.

The Committee also took up the matter of increasing our membership and various plans were discussed. However, it was the consensus of opinion among those present that due to the present business depression it would be better to wait until Fall before starting an active campaign. It was thought better results could be obtained by personal work on the part of not only the committee and Board of Direction, but also the membership at large, until that time. It was further decided to recommend to the Board that the entrance fee of the four National Societies be remitted and their applications received without filling out the usual form as was done a year or so ago. This would encourage members of the National Societies to become members of our Society and was especially appropriate at this time due to business depression.

It was moved and carried that the recommendations of the Committee be approved and that entrance fees be remitted for members of the National Societies making application at the last meeting of the Board, to be effective during the life of this Board, namely February 1922 to January 1923.

Prof. Crabtree, Chairman of the Publication Committee reported verbally stating that the Committee was considering the matter of placing the printing contract for the coming year and hoped to be able to close at a price which would mean a material saving to the Society. The Committee is also considering calling a meeting to be held under the auspices of the Associated Engineering Societies of Pittsburgh at which Mayor Magee would address the Society on civic matters of interest to the engineering profession.

Mr. Hawley, Chairman of the Finance Committee presented the following report.

For the past two years the finances of our Society have not been in satisfactory condition. This fact has been realized by the Board of Direction and it was felt that it was caused by the increased costs of supplies, etc. due to the war, particularly the increased prices for printing. The matter was referred to the Finance and House Committees and considered jointly by them during the past year, and the work of that Committee, particularly the tabulation of receipts and expenses has been of much assistance to the present committee.

At the beginning of the present year the Society was indebted to its permanent fund for $2400 which has been borrowed from that fund in order to pay for the rugs purchased about two years ago and to meet current expenses There was also $250 of entrance fees and $900 of life memberships owed to the permanent fund, making a total of $3500. In addition to this, bills for the year 1921 were carried over unpaid amounting to $2500 and this does not include the cost of publishing the proceedings for the latter part of 1921, which had been delayed on account of the inability of the printer to get them out. This will amount to about $1600 or $1700, but will be offset to a certain extent by that part of the proceedings of 1922 which will remain unpublished on Jan. 1, 1923.

The figures prepared by the Finance and House Committees last year were used as a basis for a tabulation and figures added to bring the table down to date. Copy of this table accompanies this report. A comparison of the receipts as shown in column E of this table, which receipts do not include Banquet Receipts nor Entrance Fees, with the expenses shown in Column Q, show at once that when the banquet receipts and entrance fees are not included the Society has met with a loss in ten out of fourteen years from 1908 to 1921 inclusive; that this loss has ranged from $56 in 1911 to $2315 in 1921; and this latter figure does not include the unpaid bills on January 1, 1922. Column F and R show the total receipts and expenses respectively per member for the various years, and Column T shows the gain or loss per member. A further study was made by adding the profit or loss from banquet as shown in column U to the figures in column S. These totals are shown in column AA column BB given the same results per member.

From the above it seems evident that we have been deceiving ourselves as to the relation of receipts and expenses and the financial condition of the Society including the receipts from entrance fees, which receipts cannot be used for current expenses, but under Section 7, of Article 4 of our By Laws, must be placed in the permanent fund, only the income from which is used for general expenses.

The condition which we have pointed out above demands the immediate attention of the Board. The remedy is either an increase in revenue or a reduction in expenses. The only manner in which our revenue can be materially increased is either by increasing the dues or increasing the number of members of the Society. Your Committee has given careful attention to this matter of an increase in dues and is of the opinion that an increase at this time is not wise. Furthermore, such an increase could not become effective before Jan. 1, 1923. It does believe, however, that if a sincere effort to increase the membership is made, in which the Board could secure the active co-operation of the membership, it would be possible to materially increase the number of members within the next two years.

In making this rather lengthy report your Committee has endeavored to present to the Board as briefly as possible the pertinent facts as to the Society's finances. While the condition is unfortunate, it is not serious. We hope that the members of the Board will give the matter careful consideration and give the Finance Committee the advantage of any suggestions which will be helpful.

On motion the meeting adjourned at 5:45 P. M.

K. F. Treschow, *Secretary.*

JOINT MEETING CIVIL SECTION AND PRACTISING ENGINEERS' SECTION.

The regular bi-monthly meeting of the Civil Section and the Practising Engineers' Section was held in the Blue Room, William Penn Hotel, Tuesday March 14th at 8:20 P. M., Chairman C. M. Reppert presiding, 96 members and visitors being present.

The minutes of the last meeting of the Civil Section held Feb. 14th were read and approved.

Mr. Reppert then introduced Mr. F. G. Ross, Chairman of the Practising Engineers' Section who then took charge of the meeting.

No further business coming before the Sections, Mr. R. L. Humphrey, Chairman of the Board for the Registration of Professional Engineers and Land Surveyors, addressed the Sections on the subject of Registration of Engineers and Land Surveyors.

The ensuing discussion was participated in by: J. N. Chester, Cons. Engr., John N. Chester, Engineers; G. W. Case, Professor, Sanitary Engineering University of Pittsburgh; A. E. Duckham, Consulting Civil Engineer; J. B. Crane, Engr., George T. Ladd Co.; J. Bradley Mandeville, Chf. Engr, T. W. Phillips Gas & Oil Co., Butler, Pa.; J. P. Leaf, City Engr., Beaver Falls, Pa.; A. E. Blake, Pgh. Representative, U. G. I. Contracting Co.; A. R. Raymer, Chf. Engr., P. & L. E. R. R. Co.; Edward Godfrey, Struct. Engr., Robert W. Hunt & Co.; W. C. Hawley, Chf. Engr. & Gen. Supt., Pennsylvania Water Co.; F. G. Ross, Civil Engineer, Pittsburgh, Pa.; Samuel E. Duff, Consulting Civil Engineer; P. W. Price, Asst. Engr., Allegheny County Engineer's Office; E. J. Iiams, Civil Engineer, Donora, Pa.; S. D. Foster, Consulting Highway Engineer and the author.

On Motion, duly seconded and carried, a vote of thanks was extended to Mr. Humphrey for coming to Pittsburgh on this occasion.

The meeting adjourned at 10:01 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING.

The 402nd regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, March 21st, at 8:00 P. M., President H. D. James presiding, 86 members and visitors being present.

The Minutes of the last regular meeting held Feb. 21st, were read and approved.

The Board of Direction reported the election of five applicants to the grade of Member, three to the grade of Associate Member and two to the grade of Junior, and the receipt of eight applications for membership. Transfer to higher grade of one member and the receipt of fifteen resignations, seven of which were accepted.

No further business coming before the Society, the papers of the evening—The Appraisal of Oil and Gas Properties by Roswell H. Johnson, Johnson, Huntley & Sommers, Pittsburgh, Pa., and Application of Appraisal Methods to Rate Making, Federal Taxation and Commercial Purposes by Paul Ruedemann, Geologist and Appraiser, Johnson, Huntley & Sommers, were presented.

The ensuing discussion was participated in by: M. R. Scharrff, Asst. Chf. Engr., Morris Knowles Inc.; H. D. James, Mgr., Control Engineering Dept., Westinghouse Elec. & Mfg. Co.; W. A. Weldin, Blum-Weldin & Co.; Winters Haydock, Engr., Citizens' Committee on City Plan of Pittsburgh; F. A. Simmons, Asst. Professor, Civil Engineering, Carnegie Inst. of Technology; and the authors.

On motion, duly seconded and carried a vote of thanks was extended to Mr. Johnson and Mr. Ruedemann for their very excellent papers.

The meeting adjourned at 10:00 P. M.

K. F. Treschow, *Secretary.*

MINING SECTION.

The regular bi-monthly meeting of the Mining Section was held in the Blue Room, William Penn Hotel, Tuesday, March 28th, at 8:15 P. M. Chairman W. A. Weldin presiding, 90 members and visitors being present.

The Minutes of the last regular meeting held Jan. 31, 1922 were read and approved.

No further business coming before the Section, the paper of the evening on The Use of Cement and Concrete in Underground Workings was presented by Mr. Robert Linton, Mining Engineer, New York, N. Y.

The ensuing discussion was participated in by: H. N. Eavenson, Cons. Mining Engr., Howard N. Eavenson & Associates; Graham Bright, Gen. Engr., Westinghouse Elec. & Mfg. Co.; A. J. White, Mgr., Cement Gun Construction Co.; G. E. Flanagan, Mech. Engr., Heyl & Patterson, Inc.; J. R. Elliott, Baton & Elliott; J. W. Paul, Chief Coal Mining Investigations, U. S. Bureau of Mines; S. L. Goodale, Professor of Metallurgy, University of Pittsburgh; F. A. McDonald, Chf. Engr. & Gen. Supt., National Mining Co., Morgan, Allegheny Co., Pa.; W. A. Weldin, Blum-Weldin & Co.; Frederic Crabtree, Professor Mining & Metallurgy, Carnegie Inst. of Technology; Edward Steidle, Assoc. Professor, Mining Engineering, Carnegie Inst. of Technology; and the author.

On motion the meeting adjourned at 10:35 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor "A", William Penn Hotel, Tuesday, April 18th at 4:40 P. M., President H. D. James presiding, Messrs. Crabtree, Hildner, Fohl, Hunter, Hobbs, Moore, Weldin, Danforth and the Secretary being present.

The Minutes of the last regular meeting held March 21st, were read and approved.

Applications for membership from the following gentlemen having been published to the Society, pursuant to the approval of the recommendations made by the Membership Committee were elected to membership.

MEMBERS

Dawson, Joseph R.
Fechheimer, Carl J.
Geeseman, Delbert B.
Jump, Edmund Percival
McMillin, Oliver B.
White, Charles M.

JUNIORS

Haines, Elmer B.
Lappin, Joseph

Applications for membership were received from the following gentlemen and were graded by the Membership Committee as follows:

MEMBERS

Bigelow, C. G.
Gibson, Merl David
Goeddel, William Adolph
Hanlon, Charles C.
Henrici, Frederick Wm.
Johns, Alexander Watson
Kendall, Verner V.
Mali, F. F.
Morton, William Alfred
McGarvey, Albert Gayton
Reich, P. J.
Rust, Stirling M.

ASSOCIATE MEMBERS

Sanville, Walter F.
Schein, Nathan

ASSOCIATES

Hersperger, Wade Wilson
Shriner, E. C.

JUNIOR

Shaw, C. H.

Applications were received from the following gentlemen asking to be transferred to higher grade and upon recommendation of the Membership Committee, they were transferred to the grade of Members.

Fatkin, Edward, Shockey
Van Deventer, Frank M.

The Secretary presented a letter from Mr. J. H. Smith requesting that he be reinstated to membership. After discussion it was moved and carried that Mr. Smith be reinstated to membership and that the Secretary advise him to that effect.

The report of the Secretary showing the financial condition of the Society March 31st, having been previously audited by the Finance Committee, was approved.

The Secretary reported verbally on behalf of the Entertainment Committee that they had under consideration a meeting to be called by the Associated Engineering Societies of Pittsburgh at which Mayor Magee is to present an address and May 11th has been set as the date of this meeting.

The Committee has also under consideration the question of Entertainment of the American Council during their meeting in Pittsburgh, May 26th and 27th.

Several inspection trips are being planned, definite announcement of which will be made later.

Mr. Fohl, Chairman of the House Committee reported an evening attendance of 113 for the month of March.

The Committee is planning a Chess Tournament within the next four or five weeks and advance announcement has already been made in the Society Notes and several entries have been received.

The attendance at our Noon-Day Luncheon has been increasing each week and we are averaging 30 to 35 a day.

Mr. Hunter, Chairman of the Membership Committee stated that one meeting of the Committee has been held to consider the applications for membership and to assign them to the various grades of membership.

The question of ways and means of increasing the membership was discussed and it was suggested that the Committee get up a list of names for approval of the Board to send engraved invitations and it was moved and carried that members send in the list to the Secretary before the Board meeting.

The Secretary was requested to mail both invitation and acceptance cards to members with the names of those who had not accepted our first invitation to join, the members to see the men to whom they were assigned and try to obtain their acceptance.

No active campaign for membership will be started until Fall.

Mr. Crabtree, Chairman of the Publication Committee reported verbally on behalf of the Publication Committee stating that the Committee had held a meeting this month at which preliminary steps were taken toward making up the program for the 1922-23 Season and the Committee hoped to have the program complete by the latter part of May.

The Secretary presented a letter from Penna. State College requesting that we appoint delegates to attend the Election of Trustees to be held Tuesday, June 13th.

After discussion the Secretary was requested to appoint two delegates from the membership who expect to attend the Commencement this year.

The Secretary presented a letter from Dr. Thomas S. Baker, Acting President, Carnegie Institute of Technology, inviting the Society to appoint delegates on the Two Conferences on Commercial Engineering to be held at Carnegie Institute of Technology on May 1st and 2nd. This Conference has been called by the United States Commission of Education. Mr. James stated that he had appointed Mr. Morris Knowles and Mr. R. L. Wilson to act as delegates, subject to the approval of the Board. It was moved and carried that the President's action be approved.

The Secretary presented a circular letter from the Federated American Engineering Societies asking our Society to secure information from the industries in Pittsburgh District to assist a special committee of the Federated Societies who is making a study of non-employment and business cycles.

After discussion, it was moved and carried that this letter be tabled.

On motion the meeting adjourned at 5:50 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section of Engineers' Society of Western Pennsylvania was held in the Georgian Room, William Penn Hotel, Tuesday, April 11th at 8:15 P. M., Mr. F. M. Van Deventer presiding in the absence of Mr. Moore, Chairman, 74 members and visitors being present.

The Minutes of the last meeting held February 7th, were read and approved.

No further business coming before the Section, the paper of the evening was presented by Mr. B. W. Kerr, President, Railway & Industrial Engineering Co., Greensburg, Pa. on "The Engineering Features of the Herrington Rocking Cableway."

Discussion was participated in by various members and visitors at the meeting.

On motion the meeting adjourned at 9:30 P. M.

K. F. Treschow, *Secretary.*

JOINT MEETING

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA AND PITTSBURGH CHAPTER AMERICAN SOCIETY FOR STEEL TREATING

The 403rd regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in connection with the Pittsburgh Chapter of the American Society for Steel Treating, in the Blue Room, William Penn Hotel, Tuesday, April 18th, at 8:08 P. M. President presiding, 115 members and visitors being present.

The Minutes of the last meeting held March 21st, were read and approved.

The Board of Direction reported the election of six applicants to the grade of Member and two to the grade of Junior and the receipt of seventeen applications for membership. Also the application for transfer to higher grade of two members and one reinstatement.

There being no further business the paper of the evening on "Some Applications of Electricity to the Reheating of Steels" was presented by Mr. E. F. Collins, Consulting Engineer, Industrial Heating Dept. General Electric Co., Schenectady, N. Y.

Written discussion was participated in by: W. C. Buell, Jr., Chf. Engr., Liquid Fuel Dept., George J. Hagan Co.

The Ensuing discussion was participated in by: George J. Hagan, George J. Hagan Co.; G. F. Scott, Mech. Engr., Westinghouse Elec. & Mfg. Co.; W. Trinks, Professor, Mechanical Engineering, Carnegie Institute of Technology; and the author.

On motion the meeting adjourned at 11:05 P. M.

K. F. Treschow, *Secretary.*

STEEL WORKS SECTION

The regular bi-monthly meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Georgian Room, William Penn Hotel, Tuesday, April 25th at 8:25 P. M., Vice Chairman G M. Goodspeed presiding in the absence of the Chairman, 36 members and visitors being present.

The Minutes of the last meeting held February 28th, were read and approved.

No further business coming before the Section, the paper of the evening on "The Making of Steel in India" was presented by Mr. Barton R. Shover, Consulting Engineer, Pittsburgh, Pa.

The ensuing discussion was participated in by: F. F. Espenschied, Pittsburgh District Representative, Commercial Truck Co. of Philadelphia; E. O. Mueller, Mech. Engr., Pittsburgh, Pa.; and the author.

On motion the meeting adjourned at 10:04. P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Parlor "C", Tuesday, May 16th, at 4:40 P. M., President Henry D. James presiding, Messrs. Hawley, Danforth, Hunter, Hildner, Hobbs, Moore and the Secretary being present.

The Minutes of the last regular meeting held April 18th, were read and approved.

Applications for membership from the following gentlemen, having been published to the Society, pursuant to the action of the Board at its last meeting, were elected to membership.

MEMBERS

Bigelow, Charles G.
Gibson, Merl David
Goeddel, William Adolph
Hanlon, Charles C.
Henrici, F. W.
Johns, Alexander Watson
Kendall, Verner V.
Mali, Franklin Fruit
Morton, William Alfred
McGarvey, Albert Gayton
Reich, Philip J.
Rust, Stirling M.

ASSOCIATE MEMBERS

Sanville, Walter F.
Schein, Nathan

ASSOCIATES

Shriner, Edw. C.
Hersperger Wade Wilson

JUNIOR

Shaw, C. H.

Applications for membership were received from the following gentlemen and were graded by the Membership Committee and apprpoved by the Board, as follows:

MEMBERS

Armel, James Paul
Chapman, W. B.
Kennedy, Julian Jr.
Lane. Harold
Milton, Alonzo Loring
Rice, Cyrus Wm.
Scheib, Walter H.
Yohe, J. B.

JUNIORS

Kruse, Alfred Rudolph
Leh, Alden U.
Mills, William Fleming
Scott, J. Frew

Application was received from Mr. H. M. Logan, Sr. asking to be transferred to higher grade and upon recommendation of the Membership Committee, he was transferred to the grade of Member.

The report of the Secretary showing the financial condition of the Society, April 30th, having been previously audited by the Finance Committee, was approved.

The Entertainment Committee reported a paid attendance of 135 at the Smoker held May 11th. Our expenses were $112.25 and the receipts $135.00, leaving a net profit of $22.75.

The Committee held one meeting during the past month at which a special committee to have charge of the dinner May 26th was appointed, Mr. G. D. Bradshaw Chairman with J. C. Hobbs and G. G. Coolidge. The Sub-committee held one meeting and completed preliminary arrangements for the dinner.

The Committee also published an announcement regarding social activities of the Society requesting each member to fill out and return card checking off such activities in which they were particularly interested. Up to this time about 250 replies have been received, which will be tabulated and a detailed report presented at the next meeting of the Board, giving those activities in which it is believed we can successfully continue.

Mr. Hawley, Chairman of the Finance Committee stated verbally that the only work accomplished by the Committee during the past month was the placing of estimated budget and the amounts spent to date on the finance statement. It will be noted that our expenditures under office and miscellaneous are about $400.00 in excess of the estimated budget, but this is accounted for by our moving and the audit of the accounts of the Society for the past eighteen months.

The House Committee reported an evening attendance of 87 for the month of April.

The Annual Chess Tournament was started Saturday afternoon May 13th with 18 entries. Mr. Stucki has offered a second prize to be given the winner of a second tournament to be played by those who were eliminated in the first series, and as reported before the Chairman of the House Committee has offered a first prize for the winner of the main tournament.

The Committee recently arranged with Mr. Butler, Manager of the Hotel for three electric fans, which has greatly improved the air in our room.

Mr. Hunter, Chairman of the Membership Committee stated that one meeting of the Committee had been held to consider the applications received and to assign them to the different grades of membership.

The question of granting privileges of the Society to Army, Ordnance and Naval Engineers in the District was brought up and discussed and it was moved and carried that the Committee recommend to the Board that the Secretary be authorized to write Government Engineers extending to them the privileges of the Society and that the Chief of Bureaus in Washington also be notified of our action.

After discussion it was moved and carried that the report of the Committee be approved in principle and that the Committee be instructed to go into this matter further and report back to the Board as to just what men this invitation is to be extended. It was suggested that they get in touch with Major Bell and secure his suggestions.

The Secretary presented a letter from the National Conference on

City Planning suggesting that we appoint delegates to attend the conference to be held in Springfield, Mass., June 5th to 7th.

After discussion it was moved and carried that the Secretary be instructed to endeavor to find some of our members who are attending the Conference and ask them to represent the Society.

On motion the meeting adjourned at 5:30 P. M.

K. F. TRESCHOW, *Secretary*.

CIVIL SECTION.

The regular bi-monthly meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, May 2nd at 8:13 P. M., Vice Chairman H. R. Thayer presiding in the absence of the Chairman, 105 members and visitors being present.

The Minutes of the last regular meeting held March 18th were approved without reading.

No further business coming before the Section, the main paper of the evening was presented on "Water Front Improvements in the Down-Town District" was presented by Mr. E. K. Morse, Consulting Engineer, Pittsburgh, Pa.

The Chair called upon Mr. L. W. Wallace, Executive Secretary of the Federated American Engineering Societies, who was visiting the city for a short talk.

Written discussion was presented on the various subjects as follows: Major J. F. Bell, Dist. Engr., U. S. Engineer Office, Pittsburgh, Pa.; "The Down-Town Street System and Co-ordination With the Major Street Plan", By Winters Haydock, Engr., Citizens' Committee on City Plan of Pittsburgh; "Terminal Facilities", E. Logan Hill, Sales Mgr., Heyl & Patterson, Inc., New York, N. Y.; "Sewage and Drainage", By J. M. Rice, Civil & Sanitary Engineer, Pittsburgh; "Co-ordination of the General Plan", By Frederick Bigger, Architect and Town Planner, Citizens' Committee on City Plan of Pittsburgh; "Flood Prevention and River Hydraulics", By Morris Knowles, Consulting Engineer, Pittsburgh; "What Pittsburgh Needs in the Way of Transportation", By A. H. Burchfield, 1st V. P., Jos. Horne Company, Pittsburgh; "Illustrative Example of Terminal Construction", By Harry J. Lewis, Consulting Engineer, Pittsburgh.

On motion the meeting adjourned at 10:55 P. M.

K. F. TRESCHOW, *Secretary*.

REGULAR MONTHLY MEETING

The 404th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, May 16th, at 8:06 P. M. President, H. D. James presiding, 45 members and visitors being present.

The Minutes of the last regular meeting held April 18th were read and approved.

The Board of Direction reported the election of thirteen applicants to the grade of Member, two to the grade of Associate Member, two to the grade of Associate and one to the grade of Junior and the receipt of twelve applications to membership, and transfer to higher grade of one member.

There being no further business before the Society the paper of the evening on Aerial Tramways was presented by Mr. F. C. Carstarphen Tramway Engineer, Trenton Works, American Steel & Wire Co., Trenton, N. J.

The ensuing discussion was participated in by: W. M. Austin, Elec. Engr., Westinghouse Elec. & Mfg. Co.; Max von Bernewitz, Mining & Metallurgical Engr., U. S. Bureau of Mines; A. E. Crockett, Mgr., Bureau of Instruction, Jones & Laughlin Steel Co.; G. E. Flanagan, Mech. Engr., Heyl & Patterson, Inc.; H. D. James, Mgr., Control Engineering Dept., Westinghouse Elec. & Mfg. Co.; F. M. Van Deventer, Engr., Power Department, National Tube Co.; and the author.

On motion of Mr. Flanagan, duly seconded and carried, a vote of thanks was extended to Mr. Carstarphen for his very interesting paper.

On motion the meeting adjourned at 10:25 P. M.

K. F. TRESCHOW, *Secretary.*

MINING SECTION

The regular bi-monthly meeting of the Mining Section of the Engineers Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Wednesday May 31st,, at 8:15 P. M. Chairman W. A. Weldin presiding, 38 members and visitors being present.

The minutes of the last regular meeting held March 29th, were read and approved.

No further business coming before the Section, the paper of the evening was presented by Mr. J. F. Joy, President, Joy Machine Co., on "Substitution of Mechanical Energy for Human Energy in Underground Loading."

The ensuing discussion was participated in by: Julian Kennedy, Cons. Engr., Pittsburgh, Pa.; E. H. Coxe, Gen. Mgr,, Snowdon Coke Co., Brownsville, Pa.; W. A. Weldin, Blum-Weldin & Co.; F. A. Barry, Salesman, Westinghouse Elec. & Mfg. Co.; H. N. Eavenson, Consulting Mining Engineer; N. F. Hopkins, Harrop & Hopkins; Norton A. Newdick, Consulting Mechanical Engineer, Columbus, Ohio; and the author.

There being no further business, on motion the meeting adjourned at 9:47 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, William Penn Hotel, Parlor "F", Tuesday, June 20th at 4:40 P. M., President H. D. James presiding, Messrs. Danforth, Hawley, Hildner, Crabtree, Moore, Kneass, Knowles and the Secretary being present.

The Minutes of the last regular meeting held May 16th were read and approved.

Applications for membership from the following gentlemen, having been published to the Society pursuant to the approval of the Board of the recommendations made by the Membership Committee, were elected to membership.

MEMBERS

Armel, James Paul
Chapman, W. B.
Kennedy, Julian, Jr.
Lane, Harold
Milton, Alonzo Loring
Rice, Cyrus William
Scheib, Walter H.
Yohe, J. B.

JUNIORS

Kruse, Alfred Rudoph
Leh, Alden U.
Mills, William Fleming
Scott, J. Frew

Applications for membership, were received from the following gentlemen and were graded by the Membership Committee as follows:

MEMBERS

Beech, Howard Lindsley
Croak, John J.
Hartson, Door Parmelee
Hergett, Harry Lynn
Shoffstall, A. S.
Taylor, Ernest Succop
Watt, Scott Nevin

ASSOCIATE

Troxell, William B.

JUNIORS

Joos, Charles Emil
DeMay, John A.
Ross, Theodore H.

Applications for reinstatement were received from the following gentlemen and upon recommendation of the Membership Committee, they were reinstated to membership.

J. E. Babb B. L. Schwartz

Letters of resignation were received from the following gentlemen upon recommendation of the Membership Committee were ordered accepted.

E. C. Cook
G. R. Harlow
G. A. Pool
H. C. Witte
V. Young

The Secretary reported the death of Mr. J. S. Seaman, who joined the Society, October 1898 and died June 15, 1921. It was moved and carried that Prof. Crabtree write a memoir of Mr. Seaman.

The report of the Secretary showing the financial condition of the Society May 31st, having been previously audited by the Finance Committee, was approved.

COMMITTEE REPORTS

The Secretary reported in the absence of Mr. Ladd, Chairman of the Entertainment Committee, that there was deficit of $35.00 in connection with the dinner held in honor of the Executive Board of the Engineering Council on May 26th.

The Committee has also been endeavoring to arrange some inspection trips, but due to the coal strike and unsettled labor situation, the majority of the companies requested that we wait until Fall to visit their plants. It is hoped that several trips can be arranged in the months of September and October. The committee is also considering arrangements for a boat excursion to be held in September.

Mr. Hawley, Chairman of the Finance Committee, reported verbally, calling attention to the fact that we had somewhat exceeded our budget, but it was hoped that during the Summer months we would be able to reduce this amount to some extent. In connection with report of deficit on dinner held May 26th, it was suggested that the Finance Committee pro-rate the deficit among the organizations belonging to the Associated Engineering Societies and further that a statement be sent them for services rendered by the Society since the organization of the Association. The Finance Committee was authorized to decide what this amount should be.

The House Committee reported an evening attendance of 176 for the month of May. In addition to this the Secretary stated that the Annual Chess Tournament was about completed and the attendance at our noon day luncheons is still increasing, the highest being 52.

Mr. Hunter, Chairman of the Membership Committee, reported that a meeting of the Committee had been held and applications received assigned to the various grades of membership, as well as five resignations acted upon.

Prof. Crabtree, Chairman of the Publication Committee reported verbally that a meeting would be held within the next week or two, at which time it was hoped to be able to complete the program for the ensuing year.

In accordance with instructions from the Board at its last meeting, the Membership Committee took up with Major Bell the question of extending the privileges of the Society membership to certain Army and Naval Officers situated in the Pittsburgh District with the result that Major Bell recommended that this invitation be extended to commissioned officers in the United States Army, Navy and Marine Corps who are on duty in the Pittsburgh District and doing engineering work. Major Bell stated that he believed there were about six such men in Pittsburgh. After discussion it was moved and carried that all privileges of membership be extended to the officers in Pittsburgh coming under Major Bell's recommendation.

Mr. James brought up the question of a letter he had received from Mr. Hawley in regard to the appointment of an engineer on the Pennsylvania State Public Service Commission. Mr. Hawley recommended that this Society write Governor Elect Pinchot, asking that he give the engineering profession adequate representation on this Board. Further that we write the various engineering societies in the State asking that they take similar action.

After discussion it was moved and carried that the President be authorized to get in touch with the other sections of the National Societies belonging to the Associated Engineering Societies of Pittsburgh and secure their approval of this action, after which a letter be sent as suggested, over the signature of the Associated Engineering Societies of Pittsburgh.

It was further suggested that Mr. Hawley dictate the letter to be sent to various organizations.

On motion the meeting adjourned at 5.45 P M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Hawaiian Room, William Penn Hotel, Tuesday, June 6th, at 8:20 P. M., Chairman W. E. Moore presiding, 43 members and visitors being present.

The Minutes of the last regular meeting held April 5th, were read and approved.

No further business coming before the Section, the paper of the evening on Factors Affecting the Use of Ail in Oil Burning with Comparison of Cost was presented by Mr. W. C. Buell, Jr., Vice President, Buell-Scheib-Mueller, Inc., Pittsburgh, Pa.

The ensuing discussion was participated in by: B. B. Weinberg, Supt. Heppenstall Forge & Knife Co.; C. W. Heppenstall, Treas. & Gen. Mgr. Heppenstall Forge & Knife Co.; F. K. Howell, Asst. Supt. Compressing Stations, Philadelphia Company; and the author.

There being no further discussion, the meeting adjourned at 9:30 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 405th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room William Penn Hotel, Tuesday, June 13th at 8:15 P. M. President Henry D. James presiding, 42 members and visitors being present.

The Minutes of the last regular meeting held May 16th were read and approved.

The Board of Direction reported the election of twelve applicants to the grade of Member, two to the grade of Associate Member, two to the

grade of Associate and one the grade of Junior, and the receipt of twelve applications for membership, also the transfer to higher grade of one member.

No further business coming before the Society, the paper of the evening on "Recent Developments in Concrete" was presented by Mr. H. C. Boyden, Portland Cement Association, Pittsburgh, Pa.

The ensuing discussion was participated in by G. E. Flanagan, Mech. Engr., Heyl & Patterson, Inc.; J. J. Wilson, Research Engr., National Tube Co.; Edward Godfrey, Struct. Engr., Robert W. Hunt & Co.; W. T. Hurtt, Mech. Engr., Pittsburgh, Pa.; E. E. Duff, Jr., Dist. Engr. Eastern Paving Brick Manufacturers Assoc.; C. N. Haggart, Struct. Engr., Pittsburgh; and the author.

On motion duly moved and seconded, a vote of thanks was extended to Col. Boyden for his very interesting and instructive paper.

On motion the meeting adjourned at 10:25 P. M.

K. F. Treschow, *Secretary.*

STEEL WORKS SECTION

The regular bi-monthly meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, June 20th, at 8:15 P. M., Chairman Strickland Kneass, presiding, 43 members and visitors being present.

The minutes of the last meeting held April 25th, were read and approved.

No further business coming before the Section, the paper of the evening on "Observations at German Iron & Steel Works with Special Reference to Heat Economy" was presented by K. Huessener, Manager, American Heat Economy Bureau, Pittsburgh, Pa.

Written discussion was presented by: A. E. Blake, Pgh. Representative U. G. I. Contracting Co.

The ensuing discussion was participated in by: W. Trinks, Professor, Mechanical Engineering, Carnegie Inst. of Technology; Walter DeFries, Engr., Blaw Knox Company; Frederic Crabtree, Professor, Mining & Metallurgy Carnegie Inst. of Technology; T. W. Brooke, Electrical Engineer, Pittsburgh, Pa.; and the author.

On motion the meeting adjourned at 10:25 P. M.

K F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor "A", William Penn Hotel, Tuesday, Sept. 19th, at 4:30 P. M., President Henry D. James presiding, Messrs. Knowles, Crabtree, Stucki, Fohl, Hildner, Hobbs, Hunter, Hawley, Danforth, Moore, Weldin, Ross and the Secretary being present.

The Minutes of the last meeting held June 20th, were approved without reading.

Applications for membership from the following gentlemen, having been published to the Society, pursuant to the approval of the Board of the recommendations made by the Membership Committee, were elected to membership.

MEMBERS

Beach, Howard Lindsley
Croak, John J.
Hartson, Door Parmelee
Shoffstall, A. S.
Taylor, Ernest Succop
Watt, Scott Nevin

ASSOCIATE

Troxell, William B.

JUNIORS

DeMay, John A.
Joos, Charles Emil
Ross, Theodore H.

Applications for membership were received from the following gentlemen and were graded by the Membership Committee as follows:

MEMBERS

Adams, Henry Clay
Alford, Newell Gilder
Barnes, Henry Proctor
Fellowes, Collingwood
Fuller, C. Park
Linn, Guy Fulton
Rainsford, Ralph
Southard, Claude Frederick
Stone, Edmund C.

ASSOCIATE MEMBERS

Rogers, Clarence B.
Burrage, Claude J.

ASSOCIATE

Richard, L. Ralph

JUNIORS

Sanders, Elmer Nason
Taylor, Eugene Avery

The Secretary reported the death of the following members.

Follet, Louis. Joined Sept. 1916. Died Aug. 17, 1922.
Chalfant, J. G. Joined June 1904. Died Aug. 26, 1922.
Snyder, W. E. Joined Feb. 1899. Died June 24, 1922.

It was moved and carried that Mr. A. L. Hoerr and Mr. L. F. W. Hildner be asked to write a memoir of Mr. Snyder and Mr. F. B. Chalfant and Mr. V. R. Covell, one of Mr. J. G. Chalfant.

The reports of the Secretary showing the financial condition of the Society June 30th, July 31st, and August 31st, having been previously audited by the Finance Committee, were approved.

In accordance with Article 9, Section 1, of the By-Laws of the Society, in reference to amendments, the following resolution was presented as follows:

Resolved: That Section three (3) of Article four (IV) be amended to read as follows:

ANNUAL DUES

	Entrance Fee	Resident	Non-Resident
Honorary Member	None	None	None
Member	$10.00	$15.00	$10.00
Associate Member	10.00	15.00	10.00
Associate	10.00	12.50	7.50
Junior	None	10.00	7.50
Student Junior	None	3.00	3.00

Members, Associate Members and Juniors who are enrolled in more than one section, shall pay annual dues of $2.50 for each additional section in which they are enrolled.

May be paid in equal amounts Jan. 1st and July 1st.

J. C. Hobbs
W. E. Fohl
L. F. W. Hildner
F. G. Ross
Morris Knowles
W. C. Hawley
W. A. Weldin
J. A. Hunter
G. H. Danforth
Fred Crabtree

After a general discussion, it was moved and carried that the resolution be unanimously adopted and submitted at the regular meeting of the Society to be held this evening with the statement that it has been approved by the Board.

Mr. Knowles, Chairman of the Civic Affairs Committee reported that a meeting had been held on Sept. 15th to consider and act upon a letter received from the Citizens' Committee on City Plan of Pittsburgh requesting the Society to endorse their action in sending a letter to Council asking that a comprehensive program on Playground Development be adopted before any further expenditures be made. Inasmuch as this was a matter of civic interest the Committee felt that it should be referred to the Governing Council of the Associated Engineering Societies of Pittsburgh with the recommendation that they approve the action taken by the Citizens' Committee.

The Committee also took up the matter of a letter received from the Dept. of City Planning of the City of Pittsburgh, asking the Society to arrange for a meeting at which a speaker from their organization might talk on the proposed Zoning Ordinance, which is to be submitted to Council in the near future. The Committee also referred this matter to the Governing Council with the recommendation that the meeting be held.

The Secretary reported verbally on behalf of the Entertainment Committee stating that it was the intention of Mr. Ladd to call a meeting in the near future in order to make preliminary arrangements for the Annual Banquet. The Committee also has under consideration several inspection trips and some other form of entertainment during the fall and winter season.

Mr. Fohl, Chairman of the House Committee, reported an evening attendance of 347 for the months of June, July and August—133 in June, 116 in July and 98 in August. Mr. Fohl also stated that the attendance in the rooms during the day time was increasing as well as the attendance at the noon luncheons.

Mr. Hunter, Chairman of the Membership Committee, reported that a meeting of the Committee had been held to go over the applications received since the last meeting of the Board and make assignment to the various grades of membership. Also to act upon resignations received.

Prof. Crabtree, Chairman of the Publication Committee, reported that no meetings of the Committee had been held during the summer, but that the program as arranged in the Spring gave promise of being carried out as scheduled. The Committee is also endeavoring to arrange a series of meetings in regard to the future of Pittsburgh, and hopes to make definite announcement as to speakers, subjects, etc. in the near future.

The Secretary presented the following report on behalf of the Medal Awards Committee:—

August 14, 1922.

To the Board of Direction,

Engineers' Society of Western Pennsylvania.

Dear Sirs:

A meeting of the Medal Awards Committee was held in the Society Rooms, William Penn Hotel, Monday, August 14th, at 12:15 P. M. and beg to report that a Silver Medal was awarded to Mr. J. Bradley Mandeville for his paper on "Aerial Photography as Applied to Surveying."

Respectfully submitted,

L. F. Hildner, *Chairman*
Frederic Crabtree
J. C. Hobbs
Medal Awards Committee.

It was moved and carried that the report of the Committee be approved.

On motion the meeting adjourned at 5:45 P. M.

K. F. Treschow, *Secretary.*

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, Sept. 12th, at 8:20 P. M. Vice Chairman H. R. Thayer presiding, 38 members and visitors being present.

The Minutes of the last regular meeting held May 2nd, were read and approved.

There being no further business before the Section, the paper of the evening on "Local Earth Movements in Western Pennsylvania" by Mr. Leonard F. Bechtel, Chief Engineer, Allegheny County Road Dept., Allegheny County, was presented.

Written discussion was presented by H. R. Thayer, Markhart-Thayer Engineering Co.

The ensuing discussion was participated in by: Major J. Franklin Bell, Dist. Engr., U. S. Engineer Dept. U. S. Government, Pittsburgh; R. A. Cummings, Consulting Civil Engineer; V. R. Covell, Deputy County Engr., Allegheny County; R. P. Forsberg, Prin. Asst. Engr., Pittsburgh & Lake Erie R. R.; C. S. Palmer, Cons. Chemical Engr., Rock Gas Products Co., Neville Island, Pa.; and the author.

It was moved by Mr. Cummings that a Committee be appointed for the purpose of investigating slides and soils, the number of the committee and the appointment of its members being left to the Chairman. The motion was seconded and carried and the Vice Chairman stated that the matter of appointment of a committee would be referred to the Chairman for action.

On motion the meeting adjourned at 10.04 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 406th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, Sept. 19th at 8:05 P. M., President Henry D. James, presiding, 185 members and visitors being present.

The Minutes of the last meeting held June 13th, were read and approved.

The Board of Direction reported the election of six applicants to the grade of Member, one to the grade of Associate and three to the grade of Junior and the receipt of fourteen applications for membership. Also the receipt of eleven resignations.

Mr. James appointed the following gentlemen to serve on the Nominating Committee to nominate officers for the ensuing year.

Frederic Crabtree, Chairman
A. E. Crockett
H. A. Rapelye
W. M. Hall
J. M. Graves

The following resolution, which was adopted by the Board of Direction, was presented:

RESOLVED: That Section III Article IV of the By-Laws, be amended to read as follows:

The Annual Dues shall be payable on January 1st, in advance. The entrance fee and dues for the various grades of membership in the Society be as follows:

		ANNUAL DUES	
	Entrance Fee	Resident	Non-Resident
Honorary Members	None	None	None
Member	$10.00	$15.00	$10.00
Associate Member	10.00	15.00	10.00
Associate	10.00	12.50	7.50
Junior	None	10.00	7.50
Student Junior	None	3.00	3.00

Members, Associate Members and Juniors who are enrolled in more than one Section shall pay annual dues of 2.50 per each additional section in which they are enrolled.

May be paid in equal amounts Jan. 1st and July 1st.

Respectfully submitted,

J. C. HOBBS
W. C. HAWLEY
MORRIS KNOWLES
FREDERIC CRABTREE
W. E. FOHL
G. H. DANFORTH
L. F. W. HILDNER
JOHN A. HUNTER
F. G. ROSS
W. A. WELDIN

Mr. James, President, presented a silver medal awarded by the Board of Direction through its Medal Award Committee, for the best paper presented the past year to Mr. J. Bradley Mandeville for his paper, on "Aerial Photography as Applied to Surveying."

Mr. Mandeville addressed the Society as follows:

"Mr. President and members of the Engineers' Society I am not going to speak very long because I have no speech prepared, but I certainly value this medal very highly and appreciate the fact that the Committee thought me worthy of receiving it."

No further business coming before the Society, the paper of the evening on "The Australian Eclipse and the Einstein Theory" was presented by Dr. H. D. Curtis, Director, Allegheny Observatory, Pittsburgh, Pa. A general discussion followed the presentation of the paper.

On motion the meeting adjourned at 10.00 P. M.

K. F. TRESCHOW, *Secretary.*

MINING SECTION

The regular bi-monthly meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Hawaiian Room, William Penn Hotel, Tuesday, Sept. 26th, at 8:20 P. M., Chairman W. A. Weldin presiding, 61 members and visitors being present.

The Minutes of the last regular meeting held May 31st, were read and approved.

No further business coming before the Section, the paper of the evening was presented by Mr. R. W. McCasland, General Superintendent of Mines, Wheeling Steel Corporation, Wheeling, W. Va. on "The Longwall System of Mining."

The ensuing discussion was participated in by: N. G. Alford, Howard N. Eavenson & Associates; A. O. Bain, Coal Inspector, Carnegie Steel Co., Duquesne, Pa.; E. C. Hulbert, Chf. Engr., Crescent-Portland Cement Co., Wampum, Pa.; J. W. Paul, Mining Engr., U. S. Bureau of Mines; W. A. Weldin, Blum-Weldin, & Co.; G. B. Southward Chf. Engr., W. Va. Coal & Coke Co., Elkine, W. Va.; and the author.

No further business coming before the Section, on motion the meeting adjourned at 10:05 P. M.

K. F. Treschow, *Secretary*.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor "C", William Penn Hotel, Tuesday, Oct. 17th at 4:45 P. M. President H. D. James presiding, Messrs. Crabtree, Fohl, Hunter, Hildner, Terry, Reppert, Weldin and the Secretary being present.

The Minutes of the last meeting held Sept. 19th, were read and approved.

Applications for membership received from the following gentlemen, having been published to the Society, pursuant to the action of the Board of the recommendations made by the Membership Committee, were elected to membership.

MEMBERS

Adams, Henry Clay
Alford, Newell Gilder
Barnes, Henry Proctor
Fellowes, Collingwood
Fuller, C. Park
Hergett, Harry Lynn
Linn, Guy Fulton
Rainsford, Ralph
Southard, Claude Frederick
Stone, Edmund C.

ASSOCIATE MEMBERS

Burrage, Claude J.
Rogers, Clarence B.

ASSOCIATE

Richard, L. Ralph
Taylor, Eugene Avery

JUNIOR

Sanders, Elmer Nason

Application for transfer to higher grade was received from Mr. T. H. Ross and after discussion, the Secretary was requested to advise him that he had been transferred to the grade of Associate Member.

Applications for membership were received from the following gentlemen and were graded by the Membership Committee as follows:

MEMBERS

Llewellyn, Lee
Cosgrove, William H.
Trimble, Alexander F.
Southward, G. B.

ASSOCIATE MEMBERS

Hecker, Mathias
Walthour, James R.

JUNIORS

Bickel, William D.
Nourie, Leonard R.

The report of the Secretary showing the financial condition of the Society to September 30th, having been audited by the Finance Committee, was approved.

COMMITTEE REPORTS

The Secretary reported verbally on behalf of the Entertainment Committee stating that one meeting had been held at which preliminary arrangements were started for our Annual Banquet, which will be held the latter part of January. The Committee has already been in touch with several prominent speakers in regard to speaking at the Dinner and has secured the promise of one. The Committee has also under consideration the matter of inspection trips, but due to car and coal shortage, and general unsatisfactory conditions in the plants, it has been difficult to secure the consent of executives to our visiting their plants.

The Membership Committee reported that a meeting had been held to go over applications received since the last meeting of the Board to make assignment of the various grades of membership. Also to act upon any resignations received.

Mr. Theodore H. Ross was transferred to Associate Member.

Two suggestions were made as to means of increasing membership. First, that Secretary send out double postcard notice asking each member to send in one or more names of engineers who should be members of the Society and second, that a list of companies be made up and certain members of the Committee assigned to these companies to see executive heads and have them help secure new members from their engineering department. Mr. W. C. Buell and Mr. Edward Rahm were appointed a subcommittee to compile this list.

Prof. Crabtree, Chairman of the Publication Committee reported verbally stating that the meetings of the Committee had been held, but that the program as arranged gave promise of being carried out.

The Secretary presented a letter from the Engineers' Society of North Eastern Penna. in reply to our letter of last Spring asking that we communicate with Governor Elect Pinchot in regard to the appointment of one or more engineers on the Public Service Commission of Pennsylvania, stating that this matter had been discussed by their Board of Direction with the result that they advised they did not feel that it was essential to have an engineer on this commission. The Secretary stated that Mr. Hawley had asked him to refer this reply to the Board with the suggestion that the Board make an acknowledgment, stating their position and their belief that they should have an engineer on this commission.

After discussion it was moved and carried that Mr. Hawley and Mr. Knowles be appointed a sub-committee to reply to this communication.

Mr. James, reporting for the sub-committee on finances appointed

at the last meeting of the Board of Direction, stated that this committee had held a meeting and considered the possibility of soliciting donations from corporations in the Pittsburgh District to cover our present deficit, the amount suggested being $10,000. A list of 50 companies with whom the Society has a direct connection, was made up.

Mr. James stated that he would like an expression from the members of the Board as to what they thought of this plan and if they had any names to suggest that had been omitted from the list. An expression from those present favored the plan in general and Mr. James stated that he would call a meeting of the special committee in the near future to start active work along the lines suggested.

The meeting adjourned at 5:45 P. M.

K. F. Treschow, *Secretary.*

JOINT MEETING MECHANICAL SECTION AND AMERICAN SOCIETY FOR STEEL TREATING

A joint meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania and the American Society for Steel Treating was held in the Hawaiian Room, William Penn Hotel, Tuesday, October 10th at 8:15 P. M., Chairman W. E. Moore presiding, 91 members and visitors being present.

The Minutes were approved without reading.

The Chairman then turned the meeting over to Mr. Hoffman, Chairman of the Pittsburgh Section of the American Society for Steel Treating.

No further business coming before the Section, the paper of the evening was presented by Mr. W. J. Merten, Metallurgical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa. on "The Development of Helical Steel Springs for Flexible Locomotive Motor Drives."

The ensuing discussion was participated in by: C. M. Johnson, Director, Dept. of Research & Metallurgist, Crucible Steel Co. of America; T. D. Lynch, Research Engr., Westinghouse Elec. & Mfg. Co.; and the author.

On motion the meeting adjourned at 9:30 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 407th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, October 17th, at 8:05 P. M., President H. D. James presiding, 91 members and visitors being present.

The Minutes of the last regular meeting held Sept. 19th, were read and approved.

The Board of Direction reported the election of ten applicants to the grade of Member, two to the grade of Associate Member, two to grade of Associate and one to the grade of Junior, the transfer of one member to higher grade and the receipt of eight applications for membership.

No further business coming before the Society, the paper of the evening was presented by Dr. Winslow H. Herschel, Associate Physicist, U. S. Bureau of Standards, Washington, D. C. on "Testing the Quality of Lubricating Oils."

Written discussion was presented by: J. R. Buchanan, Local Engr., General Electric Co.; Max Hecht, Chemist, Duquesne Light Co.

The ensuing discussion was participated in by: LaSalle, Westinghouse Elec. & Mfg. Co.; J. E. Babb, Supt. Grease Plant and Director Chemical Laboratory, Waverly Oil Works, Prof. M. D. Hersey, Physicist, U. S. Bureau of Mines; C. J. Rodman, Chemist, Research Engineering Dept., Westinghouse Elec. & Mfg. Co.; F. K. Howell, Supt., Compressing Stations, Philadelphia Co.; W. F. Faragher, Senior Fellow, Mellon Institute and Gulf Refining Associate; C. M. White, Supt., Monongahela Connecting R. R. Co.; L. W. Heller, Acting Supt., Power Stations, Duquesne Light Co.; and the author.

On motion duly seconded and carried, a vote of thanks was extended to Dr. Herschel for his very valuable and interesting paper.

The meeting adjourned at 10:15 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Parlor E, Tuesday, Nov. 21st at 4:50 P. M., President H. D. James presiding, Messrs. Crabtree, Hildner, Danforth, Hawley, Reppert, Weldin, and the Secretary being present.

The Minutes of the last meeting held Oct. 17th, were approved without reading.

Applications for membership received from the following gentlemen, having been published to the Society, pursuant to the action of the Board, were elected to membership.

MEMBERS

Cosgrove, William H.
Lleyellyn, Lee
Southward, G. B.
Trimble, Alexander F.
Walthour, James R.

ASSOCIATE MEMBERS

Becker, Mathias

JUNIORS

Bickel, William D.
Nouris, Leonard R.

Applications for membership were received from the following gentlemen and were graded by the Membership Committee as follows:

MEMBERS

Gallinger, Walter N.
Ingram, Herschel Anthony
Mantle, Gregory Douglas
Miller, Harry R.

ASSOCIATE MEMBERS

Bradford, Herbert H.
Kirkpatrick, George Myers

ASSOCIATE

Dalzell, James Willis
Parmelee, Earle Linsley

Letter was received from Mr. J. R. Boyd asking to be reinstated to membership. He joined in February, 1908 and resigned latter part of year. Also Mr. P. A. Young, who joined in 1910 and resigned in 1914. After discussion, it was moved and carried that the Secretary be requested to write them advising of their reinstatement to membership.

Letters of resignation were received from the following and after discussion, they were ordered accepted. Dudley, S. W.; Heichert, H. S.; Layton, M. B.; Lincoln, P. M.; Schmertz, Wm. E.

The Secretary reported the death of Mr. E. B. Taylor a past president of the Society who died Nov. 8, 1922. It was moved and carried that the Secretary ask Mr. Trimble to write a memoir of Mr. Taylor.

The report of the Secretary showing the financial condition of the Society at the close of business October 31st, having been previously audited by the Finance Committee, was approved.

Mr. Hawley, chairman of the Finance Committee, reported verbally on behalf of the Committee, calling attention to the fact that by eliminating the cost of the 1921 Proceedings published this year, editorial expenses and advertising commissions, we have kept within the budget adopted by the Board.

The House Committee reported an evening attendance of 160 for the month of October.

The Membership Committee held one meeting at which the various applications received were gone over and assignment made to the various grades of membership.

One member was dropped on account of non-payment of dues and two members reinstated to membership.

The special committee assigned to make up list of companies in the district, reported that the list would be completed as soon as they secured a new membership list.

In accordance with Article 5, Section 5 of the By Laws the following report of the Nominating Committee was presented:

Nov. 15, 1922.

To the Board of Direction,
Engineers' Society of Western Penna.

Dear Sirs:

Your Nominating Committee appointed to nominate officers for the ensuing year held a meeting Nov. 15th and beg to report the following:

For President	Morris Knowles
For Vice President	W. B. Spellmire
For Treasurer	A. Stucki
For Directors	E. D. Leland
	F. I. Ellis

Respectfully submitted,

FREDERIC CRABTREE, *Chairman.*
A. E. CROCKETT,
J. M. GRAVES,
WM. F. HALL,
H. A. RAPELYE,
Nominating Committee.

It was moved and carried that the nominations be approved.

The Secretary presented the following report on behalf of the tellers appointed by the President to canvass the ballot on Transfer of Funds and Amendment to By Laws.

Nov. 15, 1922.

To the Board of Direction
Engineers' Society of Western Penna.

Dear Sirs:

In accordance with the request of the Board of Direction there was a public canvass made of the ballots on Transfer of Funds and Amendments to By Laws, with the following result:

	Yeas	Nays
Transfer of Funds	326	11
Amendments to By Laws	291	50

Respectfully submitted,

A. E. Blake, *Chairman*,
W. F. Sanville,
E. O. Mueller.

Mr. Danforth presented a verbal report of the work done by the Building Code Committee of the Dept. of Commerce, Washington, D. C. of which he is a member as a representative of this Society. This Committee is drawing up a national building code which is near completion.

The Secretary stated that Mr. C. D. Terry had requested that he present his resignation as a member of the Board of Direction as Mr. Terry felt, in justice to his company and the Society, he should resign, as he had only attended one meeting and his time was so taken up with company matters and would be during his term of office as a director, that he would probably not be able to do justice to the work.

After discussion it was moved and carried that Mr. Terry's resignation be accepted with regret and the Secretary notify him accordingly, expressing the appreciation of the Board for his cooperation during term as Director.

In accordance with Article 5, Section 13 of the By Laws, it was moved and carried that Mr. Richard Khuen, Jr., be elected to fill the vacancy caused by the resignation of Mr. Terry.

On motion the meeting adjourned at 6:00 P. M.

K. F. Treschow, *Secretary*.

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, November 7th, at 8:00 P. M., Vice Chairman Horace R. Thayer presiding, 47 members and visitors being present.

The Minutes of the last meeting held September 12th, were read and approved.

No further business coming before the Section, the paper of the evening on "Determination of Amount of Realignment, Grading, and Drainage Necessary in Connection with Road Improvement" was presented by Samuel D. Foster, Consulting Highway Engineer, Pittsburgh, Penna.

The ensuing discussion was participated in by: C. B. Stanton, Associate Professor, Civil Engineering Carnegie Inst. of Technology; L. P. Blum, Blum-Weldin & Co.; Funk, State Highway Dept. Harrisburg, Pa.; J. M. Rice, Consulting Civil Engr., Pittsburgh, Pa.; P. W. Price, Asst.

Engr., County Engineer's Office, Allegheny County; R. A. Schneider, Civil Engr. and Surveyor, Pittsburgh, Pa.; Horace R. Thayer, Markhart-Thayer Engineering Co.; Winters Haydock, Chf. Engr. Citizens' Committee on City Plan of Pittsburgh; R. V. Warren, Township Engr., Pennsylvania State Highway Dept., Harrisburg, Pa.; E. V. Braden, Engr. Pittsburgh, Chartiers & Youghiogheny Rwy. Co.; and the author.

On motion the meeting adjourned at 10:45 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 408th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, November 21st, at 8:07 P. M., President H. D. James presiding, 42 members and visitors being present.

The Minutes of the last meeting held October 17th, were read and approved.

The Board of Direction reported the eleection of five applicants to the grade of member, one to the grade of Associate Member and two to the grade of Junior and the receipt of eight applications for membership, also one reinstatement and five resignations.

The President announced that Mr. A. Stucki had won the Chess Tournament and the cup offered the winner by Mr. Fohl and that Mr. F. K. Howell had won the cup offered by Mr. Stucki in the second tournament.

No further business coming before the Society, the paper of the evening on "Planning Mass Transportation Facilities" was presented by Thomas Fitzgerald, Consulting Electrical Engineer, Pittsburgh, Pa.

The ensuing discussion was participated in by:

E. R. Jackson, Climax Engineering Co., Clinton, Iowa; W. E. Schmertz, Asst. to Mgr. Bureau of Instruction, Jones & Laughlin Steel Co.; W. M. Austin, Elec. Engr. Westinghouse Elec. & Mfg. Co.; J. M. Rice, Consulting Civil Engr., Pittsburgh; P. W. Price, Asst. Engr., County Engineer's Office, Pittsburgh; Ralph Rainsford, Chf. Engr., Philadelphia Co.; Frederic Crabtree, Professor, Mining & Metallurgy Carnegie Inst. of Technology; J. B. Crane, Engr., George T. Ladd Co.; J. R. Buchanan, Local Engr., General Electric Co.; W. F. Sanville, Pres. Specialties Co. of Pittsburgh; A. E. Anderson, Attorney, Pittsburgh; and the author.

On motion the meeting adjourned at 9:45 P. M.

K. F. Treschow, *Secretary.*

MINING SECTION

The regular bi-monthly meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Ball Room, William Penn Hotel, Tuesday, November 28th, at 8:15 P. M., Chairman W. A. Weldin presiding, 87 members and visitors being present.

The Minutes of the last regular meeting held September 26th, were read and approved.

No further business coming before the Section, the paper of the evening on "The Stripping Method of Mining Coal" was presented by Mr. Samuel A. Taylor, Consulting Mining Engineer, Pittsburgh, Pa.

The ensuing discussion was participated in by: H. L. Beach, V. P. & Sales Engr., Clark Car Co.; W. B. Spellmire,, Local Mgr., General Electric Co.; W. A. Weldin, Blum-Weldin & Co.; W. M Parkin, Engr., W. M. Parkin & Co.; G. G. Bell, Mgr., Power Dept., West Penn Power Co.; J. W. Paul, Mining Engr., U. S. Bureau of Mines; Phelan McShane, Gen. Engr., Westinghouse Elec. & Mfg. Co.; H. E. Cole, V. P. & Gen. Mgr. Harris Pump & Supply Co.; H. A. Deuel, Chf. Expediter, The Koppers Company; Thomas Higgins, Gen. Supt., City Mills, Carnegie Steel Co.; and the author.

On motion the meeting adjourned at 10:10 P. M.

K. F. Treschow, *Secretary.*

Vol. 38 FEBRUARY 1922 No. 1

PROCEEDINGS

OF THE

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

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Incorporated 1880

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American Roofer

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American Society of Mechanical Engineers. Journal

American Society of Naval Engineers. Journal

Arkitektur

Association of Chinese and American Engineers. Journal

Association of Iron and Steel Electrical Engineers. Journal

Blast Furnace and Steel Plant

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Engineering Institute of Canada. Journal

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Engineering Production

Engineering and Contracting

Engineering and Mining Journal

Engineering Review

Engineers' Club of Philadelphia. Journal

Engineers' Club of St. Louis. Journal

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Forging and Heat Treating

Franklin Institute. Journal

Gluckauf

Great Britain—Patent Office. Illustrated Official Journal

Heating and Ventilating Magazine

Industrial Management

Institution of Mechanical Engineers. Journal

Institution of Mining Engineers. Transactions

Iowa Engineering Society. Proceedings

Iron Age

Iron and Coal Trades Review

Iron Trade Review

Journal of Industrial and Engineering Chemistry.

Journal of the United States Artillery
Keramische Rundschau
L'Association des Ingenieurs. Annales
Liverpool Engineering Society Transactions
Mechanical Engineering
Military Engineer, The
Mining Congress. Journal
Mining and Metallurgy.
National Engineer
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VOL. 38 FEBRUARY 1922 No. 1

PROCEEDINGS

OF THE

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

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